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Environmental Protection Technology Series

URBAN RUNOFF TREATMENT METHODS
Volume I — Non-Structural Wetland Treatment

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December 1977

URBAN RUNOFF TREATMENT METHODS

Volume I - Non-Structural Wetland Treatment

by

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Grant No. S-802535

Project Officer

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Storm and Combined Sewer Section
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Edison, New Jersey 08817

This study was conducted
in cooperation with
Minnehaha Creek Watershed District
Wayzata, Minnesota 55391

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CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report defines the role that wetlands play in the hydrologic cycle, the character and impact of urban runoff on wetlands and the expected water quality changes by supporting wetland biota with organics and nutrients inherent in the runoff as pollutants. Biological assessments detected no environmental impacts on the wildlife or vegetation as a result of this project.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

A major concern of the Minnehaha Creek Watershed District, a natural watershed basin encompassing the area that drains into the Lake Minnetonka - Minnehaha Creek system, near Wayzata, Minnesota, is the water quality of its lakes. A significant impact on lake waters is known to be caused by stormwater runoff; providing control and treatment methods from this pollution source is a large and complex problem. The methods developed by this project may be implemented as an urban stormwater runoff control practice in many of the urban centers of the country that have unused adjacent wetlands.

This project has demonstrated the treatability and effectiveness of non-structural methods to improve the quality of stormwater runoff from urban areas using natural wetlands.

The wetland used in the study retained 77 percent of all phosphorus and 94 percent of the total suspended solids entering the site during the evaluation period.

It has been shown that the mechanism utilized by organic soils in the removal of nutrients and contaminants is the result of physical, biological and chemical mechanisms.

The physical trapping of contaminants by organic soils is the result of the characteristic fine texture of the material. The fine textures permit physical screening of sediment transported to the marsh and also tend to reduce the velocity of groundwater movement. The relatively slow velocity increases the non-structural wetland treatment methods. This report can be used as a guide in the wise and prudent use and management of wetlands, especially in urban and developing areas. A detailed environmental assessment indicated that no impacts were detected on the wildlife or vegetation as a result of this project.

This report was submitted in fulfillment of Grant No. S-802535 by the Minnehaha Creek Watershed District and their consultant, Eugene A. Hickok and Associates under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period November, 1974 to October, 1975 and work was completed as of November, 1976.

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16. ABSTRACT

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LIST OF ABBREVIATIONS

ha -- hectare
ha-m -- hectare meter
ac -- acre
ac-ft -- acre foot
kg -- kilogram
yr -- year
lbs -- pounds
cm -- centimeter
sq mi -- square mile
m -- meter
ft -- foot
cm/sec -- centimeters per second
gpd/sq ft -- gallons per day per square foot
F -- Fahrenheit
C -- Celsius
in -- inch
l -- liter
gpm -- gallons per minute
mls -- milliliters
gal -- gallon
km -- kilometer
FITC -- fluoriscene isothiocyanate

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SECTION 1

INTRODUCTION

Wetlands have been identified as having a certain capacity for the renovation of polluted waters. Urban stormwater runoff contributes significant pollution loads to urban lakes and an economically and ecologically acceptable method of control is required. This study was designated to evaluate the effectiveness of wetlands for water renovation and to identify the mechanisms and processes which take place.

A wetlands is a complex hydrologic, chemical and biological system which can result in the transformation of various elements in runoff water into compounds which may improve the quality of the discharge water or, to the contrary, have a significant deleterious effect on the quality of the water being discharged.

The wetland selected for this study has a total watershed size of approximately 28.3 ha (70 ac) with a wetland area of approximately 2.8 ha (7 ac). This conforms to the 10:1 ratio typical of many land-surface to water-surface relationships in the region. The watershed has a well developed drainage system with much of the area being drained by storm sewers. Several types of urban land use exist.

An environmental inventory was taken before and after the project and observations of the wildlife and vegetation have been made.

Flows into and from the wetland and groundwater monitoring wells were analyzed for a variety of parameters from November, 1974 through May, 1976.

The study included intensive microbial monitoring to determine the microbiological activity of the wetland and its importance to the nutrient cycle. A unique staining method called "fluoriscene isothiocyanate total count" (FITC) was used which gives a one-step method of counting the bacteria population in soil and water samples. Microbial numbers together with nutrient loads and carbon dioxide production were utilized to determine the capacity of the microbial community to utilize stormwater loads.

The primary benefits from this study are the identification and determination of the feasibility of improving the quality of stormwater runoff by utilizing natural wetlands. Scientific data required to help justify the protection of natural wetlands were also obtained.

SECTION 2

CONCLUSIONS

1. The mechanism for the renovation of stormwater by non-structural wetlands appears to be a combination of physical entrapment, microbial transformation and biological utilization.

2. The annual runoff coefficients ranged from 0.07 for the open space and single family drainage group to 0.32 for the shopping center and traffic corridor drainage group.

3. Groundwater discharge provides 18 percent of the total water runoff input to the Wayzata wetland.

4. The tributary phosphorus loading ranged from 0.11 kg/ha/yr (0.60 lbs/ac/yr) to 0.39 kg/ha/yr (2.1 lbs/ac/yr) from the undeveloped and single family drainage group to the shopping center and traffic corridor drainage group respectively.

5. Evaporation rates in the wetland are greatly reduced during periods when the vegetation is dense.

6. The Wayzata wetland retained 78 percent of all total phosphorus and 94 percent of the total suspended solids entering the site during the study period.

7. The Wayzata wetlands organic soil contained approximately 2,868 kg/ha-m (780 lbs/ac-ft) of phosphorus, 5.5 times the phosphorus holding capacity indicated by phosphorus isotherms for the soil.

8. There appears to be a net loss of ammonia from the wetland which is caused by the transformation of nitrogen compounds.

9. Phosphorus and ammonia nitrogen concentrations of the discharge water do not correlate for short term, day to day, comparisons but do correlate seasonally.

10. Discharge of nutrients from the wetlands is related to the seasons.

11. The water level management technique, where effective, did appreciably increase the surface microbial activity.

12. Microbial activity decreased dramatically when wetland soils were submerged and become anaerobic.

13. Microbial activity is significantly affected by soil temperature with higher activity during warmer temperatures.

14. Surface bacteria counts appear very responsive to runoff events, possibly due to the phosphorus load, with counts increasing in number after each event.

15. The population of anaerobic organisms deep in the organic soils [76 cm (30 in)] (76 cm) illustrate a direct relationship to phosphorus concentration.

16. The microbial activity in the wetland appears to be the initial and most important mechanism for removing phosphorus from the soil water solution.

17. Phosphorus appears to be the limiting nutrient during the summer when microbial growth conditions are optimum.

18. Dewatering of the pilot zone produced approximately 2.4 times the vegetative mass produced in the control zone.

19. The biological assessments detected no environmental impacts on the wildlife or vegetation type and abundance as a result of this project.

SECTION 3

RECOMMENDATIONS

1. A general policy of wetland preservation and phosphorus removal with non-structural treatment methods should be adopted.

2. The drainage from selected wetlands should be managed and possibly be aerated before allowed to discharge to the receiving body.

3. Careful consideration must be given to the distribution of stormwater to wetlands.

4. The Wayzata wetland study should be continued to determine nutrient transformations, ammonia to nitrate conversion, the phosphorus capture mechanisms and the hydrologic balances.

5. Additional research and uniform procedures are required in the following areas:

    a. Define the various factors of the hydrologic budget of wetlands including evapotranspiration rates, evaporation rates and groundwater movement.

    b. Define the microbial activity during aerobic and anaerobic conditions for typical wetland types.

    c. Define the importance of the plant growth cycle and water level management techniques or changes in effluent water quality.

    d. Define the treatment life expectancy of the wetland and its benefits and costs in stormwater treatment.

SECTION 4

BACKGROUND

During the calendar years of 1974 and 1975 the Minnehaha Creek Watershed District, in cooperation with the Environmental Protection Agency, implemented a rigorous study designed to determine the impacts of urban stormwater runoff on the wetlands of the District.

A wetland has been defined in the new "Interim Classification of Wetland and Aquatic Habitats of the United States", by the United States Fish and Wildlife Service (1), as... "land where the water table is at, near or above the land surface long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental conditions are favorable".

The specific wetland site was selected because it, in the opinion of the researchers, best approximated a typical wetland. See Figure 1, Location Map - Minnehaha Creek Watershed District, for the location of the watershed in reference to the Minneapolis - St. Paul Metropolitan area and Figure 2, Photographic Views of Lake Minnetonka and the Wayzata wetland.

The Minnehaha Creek Watershed District encloses 47,760 ha (184 sq mi) on the western edge of the Twin Cities Metropolitan area and, since its formation, has been charged with the protection of the resources of the watershed. Consequently, it would naturally follow that the Minnehaha Creek Watershed District Board of Managers would seek definitive answers to the following questions:

1. What role do wetlands play in the watershed's hydrologic cycle?
2. What is the character of the runoff entering the wetlands?
3. What impact does the runoff have on the wetlands?
4. What impact do the wetlands have on the quality of the runoff waters?
5. Can wetlands be managed in order to enhance the quality

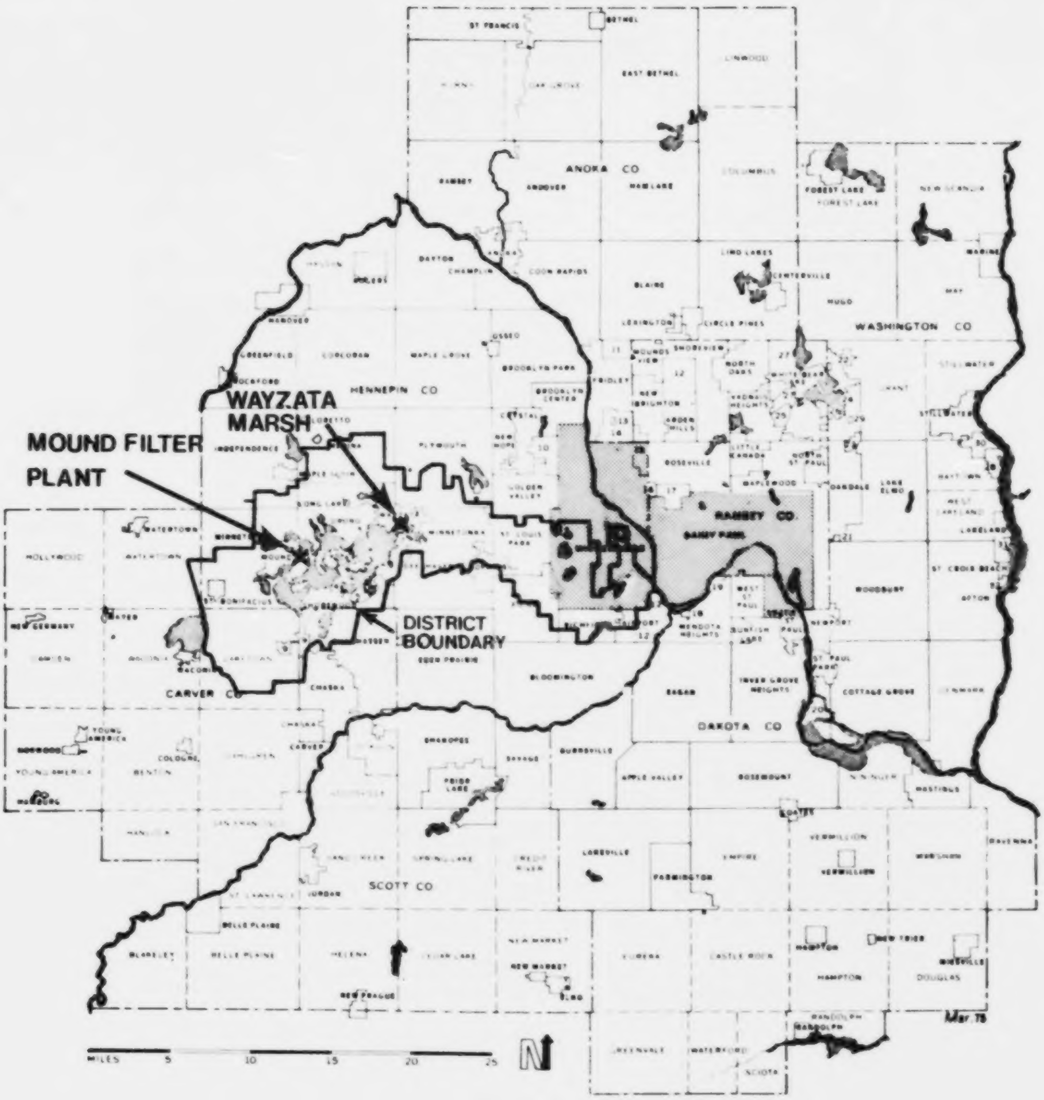

WAYZATA MARSH
MOUND FILTER PLANT
DISTRICT BOUNDARY
ANOKA CO
HENNEPIN CO
WASHINGTON CO
RAMSEY CO
CARVER CO
DAKOTA CO
SCOTT CO
MILES 5 10 15 20 25
N
Mar 75

Figure 1. Location Map - Minnehaha Creek Watershed District

a. Lake Minnetonka

b. Wayzata Wetland

Figure 2. Photographic Views of Lake Minnetonka and the Wayzata Wetland

of discharge waters?

It was the objective of this project to provide answers to the above questions as completely as possible and in a form that would assist others in the wise and prudent use of wetlands.

OBJECTIVES

The wetland project had three specific objectives that would dictate the wetland selected and formulate the study approach. Those objectives focused in these principal areas:

1. Identification and characterization of the watershed ecosystems including the hydrologic balance and the nutrient balance.
2. Interaction of hydrologic and nutrient balances with the wetland ecosystem including water level, microbial activity and nutrient discharge.
3. Implementation and evaluation of a controlled wetland ecosystem including microbial activity, nutrient balance and impacts.

METHOD OF APPROACH

The above objectives were accomplished in six major tasks, as follows:

Task I. Develop a planning and control technique for the entire project.

Task II. Select a wetland for the project and acquire access rights.

Task III. Design, purchase, construct and install the instrumentation and modifications to acquire the required data.

Task IV. Collect and analyze data, perform environmental assessments, modify data acquisition systems, review data for completeness and collect additional data.

Task V. Data evaluation, statistical data analyses and development of hydrologic and nutrient balances and models.

Task VI. Prepare a final report.

These task breakdowns were used to develop a comprehensive work plan which was used and refined as the project progressed.

SITE SELECTION

In view of the project scope, selection of a suitable wetland was critical. It was paramount that all parameters in the watershed ecosystem be identified and controlled.

A program dealing with the implementation and evaluation of a controlled ecosystem and a wetland is defined in the previously mentioned interim classification. Therefore, an extensive preliminary survey was made for several wetlands to select an ideal wetland for the project.

Four wetland sites were evaluated as potential sites. The final selection was based on 15 criteria. These criteria included:

A. Essential Characteristics:

  1. Defined wetland.
  2. Variety of urban runoff quality (highway, shopping center, commercial, residential, etc.).
  3. Well defined watershed.
  4. Well defined inlets.
  5. Well defined outlets.
  6. Public ownership.
  7. Availability.

B. Desirable Characteristics:

  1. Management size.
  2. Accessibility.
  3. Representative wetland for region (10:1 ratio).
  4. Availability of suitable sampling points.
  5. Groundwater level above lake level.
  6. Sanitary sewered region.
  7. Suitable wetland configuration for management and control area.
  8. Near laboratory facilities.

The selection was based upon the highest composite score. The scoring was as follows: Items 1 through 7 were given a value range between 1 and 10 and items 8 through 15 were given a value range between 1 and 5.

Major faults encountered in evaluation of the four wetlands were: private ownership and poorly defined inlets and outlets. Such wetlands were not acceptable for the project. The Wayzata wetland site, which had the highest composite score, was chosen for the study. See Figure 3, Location Map - Wayzata Wetland.

The Wayzata wetland is located in the heart of the City of Wayzata (population 4,500) a suburb in the Minneapolis - St. Paul Metropolitan area.

The wetland site is also located within the legal boundaries of the Minnehaha Creek Watershed District and its drainage is tributary to Lake Minnetonka.

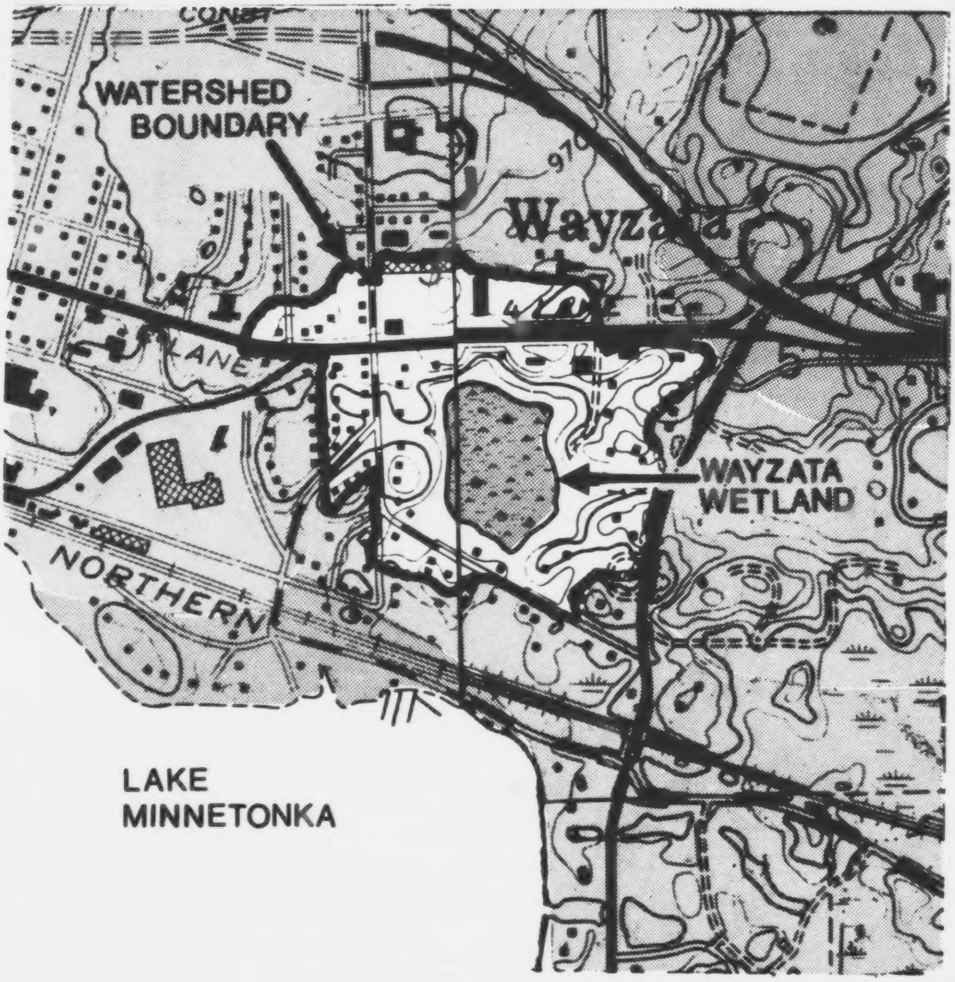

WATERSHED BOUNDARY
Wayzata
LANE
970
WAYZATA WETLAND
NORTHERN
LAKE MINNETONKA

Figure 3. Location Map - Wayzata Wetland

SECTION 5

SITE DESCRIPTION

The total watershed system utilized in the Wayzata wetland project consists of an area of 29.4 ha (72.6 ac). The total sub-basin consists of 3.06 ha (7.55 ac) of wetland and 26.3 ha (65.1 ac) of upland or tributary watershed.

SOILS AND GEOLOGY

The area of the wetland project is covered by glacial drift deposited by the Grantsberg sublobe of the late Mankato Glaciation. This drift is composed of relatively recent materials derived through the rewashing of older deposits. The parent material for soils of the wetland watershed is glacial till, glaciolacustrine deposits and organic material.

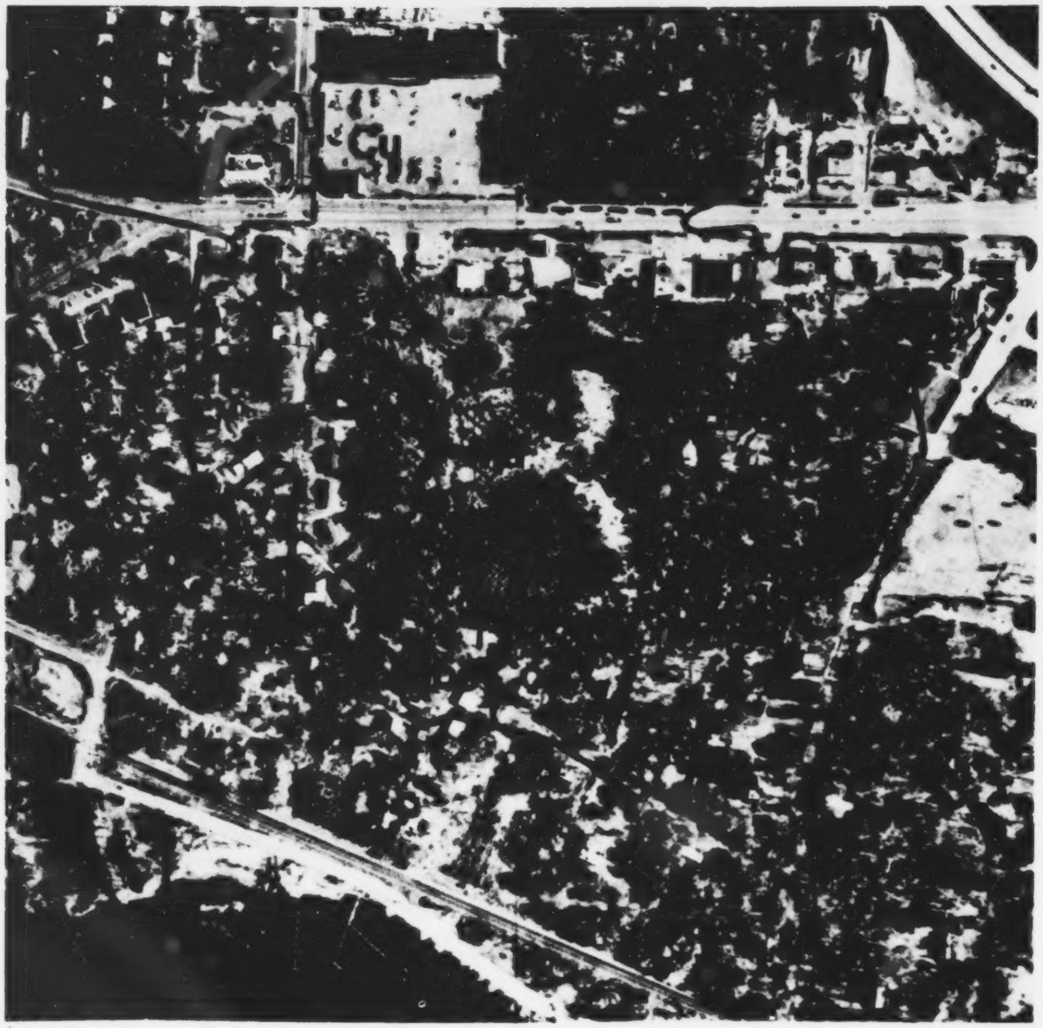
Two major soils make up the wetland watershed, they are the Hayden loam and the Cordova silty clay loam. The remainder of the soils in the watershed consist of either hydric soils or areas of cut and fill. See Figure 4, Soils Map, for the location of the specific soils.

The Hayden series consists of deep, well drained, loamy soils that formed in loamy glacial till. These gently sloping to very steep soils are convex areas on knolls and hillsides as shown in Figure 4.

The native vegetation was mixed hardwood forest. Much of this forest has given to urbanization, however, several areas of the watershed along the periphery of the wetland harbor trees that appear to be remnants of the original hardwood forest.

Hayden soils have high available moisture capacity and moderate permeability. The water table is at a depth below 1.5 m (5 ft) in all seasons. Hayden soils have low organic matter content and medium fertility. The subsoil is generally high in phosphorus.

The Cordova series consist of deep, poorly drained soils that formed in loam glacial till. These soils are on broad flats and in drainageways. As illustrated in Figure 4, the native vegetation is mixed hardwood forest.



LEGEND

Data from Soil Conservation Service

Co - Cordorva silty clay loam
Cu - Cut and fill land
HbB - Hayden loam, 2 to 6 percent slopes
HBC - Hayden loam, 6 to 12 percent slopes
HlB - Heyder complex, 2 to 6 percent slopes
Ma - Marsh

Figure 4. Soils Map

Cordova soils have high available moisture capacity, internal drainage is slow, and the permeability is moderately slow. During the wet periods, the water table is at a depth of 30.5 to 91 cm (1 to 3 ft). Fertility and organic matter content are high.

The remainder of the soils in the wetland watershed are organic soils. At this particular site these soils are formed on Glaciolacustrine deposits. The mineral soils underlying the organic soils sediments are silty clay in the upper 61 to 150 cm (2 to 5 ft) and silt loam below that depth. The peat or organic soils of the wetland range in thickness from 15.0 cm (0.5 ft) to over 6 m (19.7 ft). Values for the percent of organic matter of each separate soil profile are also shown. See Figure 5, Stratigraphic Log of Wetland Soils, for a representative log of the organic soils.

The maximum percent organic matter occurs at a depth of approximately 50 cm (1.7 ft). It is also interesting to note that the percentage of organic matter at the 400 cm (13 ft) depth is 32 percent. The peat is well supplied with calcium, but it is low in content of available potassium and phosphorus.

The importance of the above information on soils will become apparent when groundwater quality and quantity is related to the soils.

TOPOGRAPHY

The topography of the area is a result of a melting glacier. The depression forming the wetland is probably the result of stagnated ice. The actual wetland is centrally located and surrounded by moderately rolling terrain. The maximum relief is approximately 18.3 m (60 ft).

VEGETATION

The vegetation of the upland portion of the watershed basically consist of natural wooded areas with oak, elm, basswood, maple and ash as the main species. Urbanization has replaced most of the woods with lawns; however, with the exception of the fertilizer applied, the change in vegetation has had little effect on the underlying soil.

The wetland has a dense growth of natural vegetation as high as eight feet through the summer season which produces a thick vegetative cover. See Appendix A for ecology evaluations. Lush and varied, this vegetation is comprised of 38 species. Reed canary grass, willows and dogwoods are most conspicuous. Distribution of various other plant types is related to soil moisture conditions within the wetland.

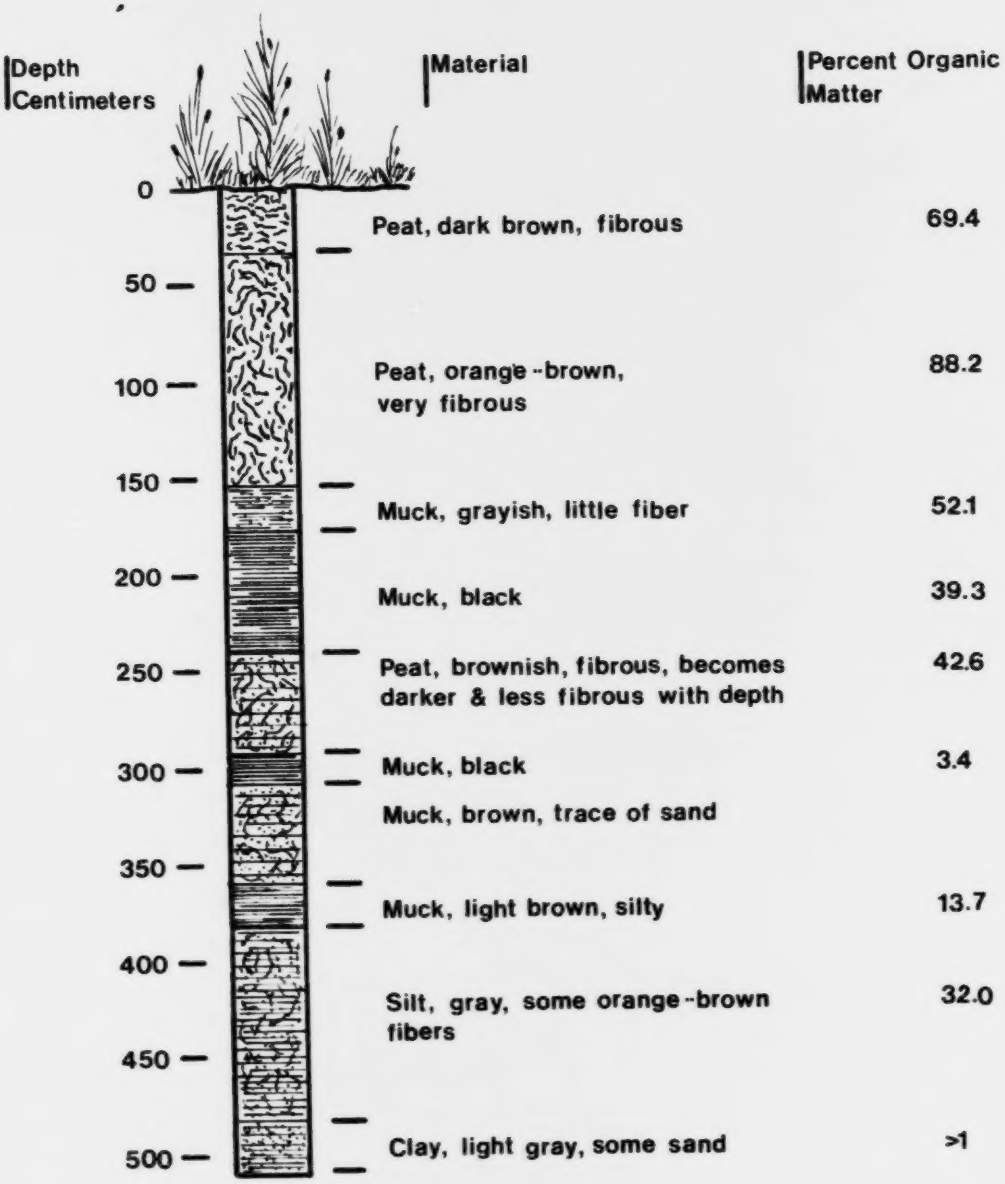

Depth Centimeters
Material
Percent Organic Matter
0
Peat, dark brown, fibrous
69.4
50
Peat, orange-brown, very fibrous
100
88.2
150
Muck, grayish, little fiber
52.1
200
Muck, black
39.3
250
Peat, brownish, fibrous, becomes darker & less fibrous with depth
42.6
300
Muck, black
3.4
Muck, brown, trace of sand
350
Muck, light brown, silty
13.7
400
Silt, gray, some orange-brown fibers
32.0
450
500
Clay, light gray, some sand
>1

Figure 5. Stratigraphic Log of Wetland Soils

Predominant vegetation in the wetlands include:

Grasses: Phlaris (reed canary);

Cattails: Typha latifolia;

Forbes: Equatorium pupureum (purple boneset),
Lythrum salicaria (purple loosestrife);

Trees and shrubs: Cornus (dogwood), Salix (willows)
Ribes (black currant), and Sambucus
canadensis (elderberry)

DRAINAGE

The wetland is directly tributary to Lake Minnetonka and has a total watershed area of 29.4 ha (72.6 ac). The subwatershed boundaries and drainage system are generally well defined with rolling topography and urban development.

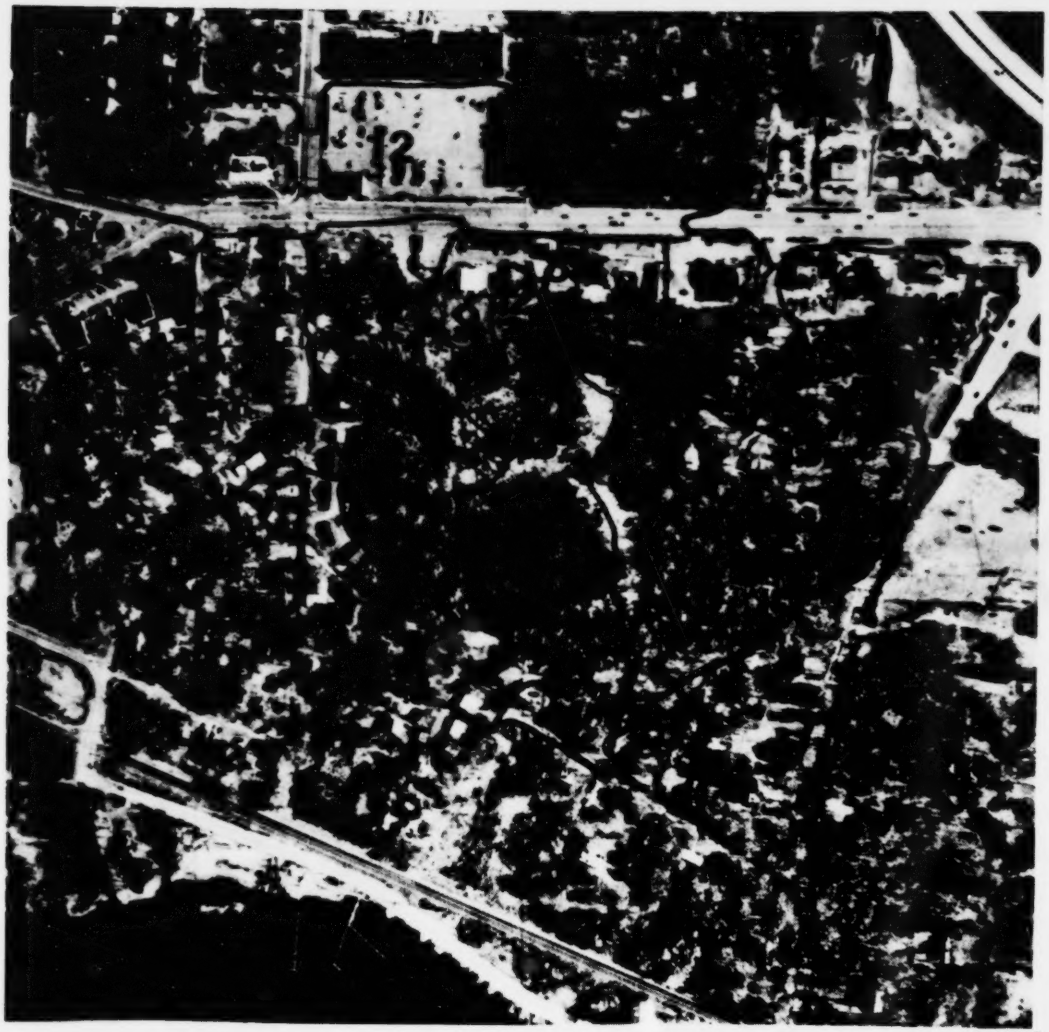
The watershed was divided into five drainage groups based upon the degree of similarity of the various subwatersheds. A total of 13 subwatersheds made up the five groups. See Figure 6, Wayzata Wetland Watershed Boundaries.

Drainage Group I includes subwatersheds 1, 2, 5 and 7. It has a total area of 8.57 ha (21.17 ac) or 29.9 percent of the total watershed area. The watersheds are typically undeveloped or have single family homes on large lots, and are heavily wooded. A typical photographic view of Drainage Groups I - IV is shown in Figure 7. This group has very low population density.

Drainage Group II includes subwatersheds 3, 4 and 11 and has a total area of 5.03 ha (12.44 ac), 17.1 percent of the total watershed. This group consists of single family homes on small lots. See Figure 7. This group has the highest population density of the wetland watershed.

Drainage Group III includes subwatersheds 6, 8 and 9 and has a total area of 4.66 ha (11.52 ac), 15.9 percent of the total watershed. This area is characterized by having approximately 50 percent occupied by small businesses located along a major traffic corridor. See Figure 7. The remaining portion consists of a very sparsely developed, heavily wooded area. A total of 44 percent of this drainage group consists of impervious cover material such as roofs, parking lots or highways.

Drainage Group IV includes subwatersheds 10 and 12 and has a total area of 8.05 ha (19.88 ac), 27.4 percent of the total watershed. The area is characterized by a major traffic corridor (U.S. Highway 12). See Figure 7. A total of 55 percent of the area in Group IV has an impervious cover.



Source: Mark Hurd

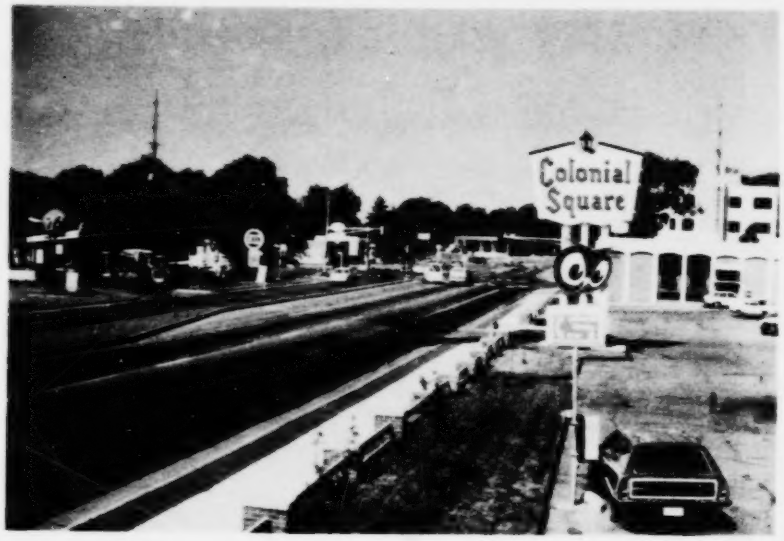
Drainage Group	Subwatersheds
I	1, 2, 5 & 7
II	3, 4 & 11
III	6, 8 & 9
IV	10 & 12
V	13

Figure 6. Wayzata Wetland Watershed Boundaries

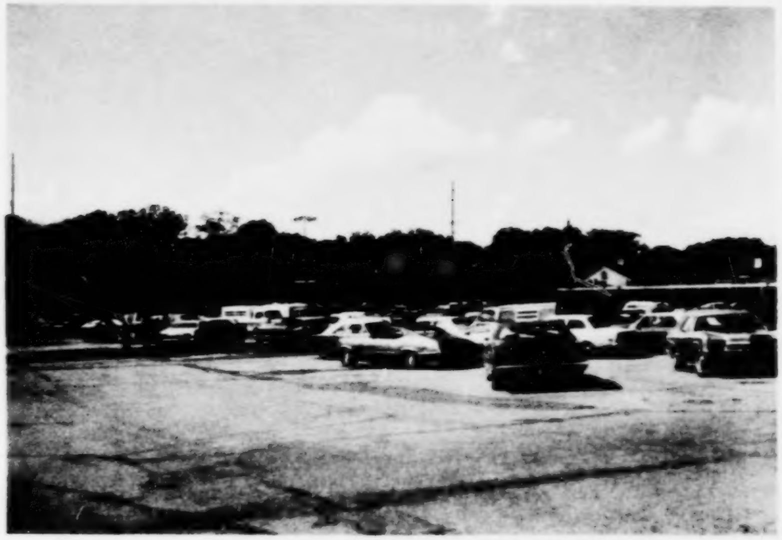
a. Drainage Group I

b. Drainage Group II

Figure 7. Typical Photographic Views of Drainage Groups I - IV


Colonial Square

c. Drainage Group III



d. Drainage Group IV

Figure 7. Continued

Drainage Group V includes subwatershed 13, the wetland itself, and has an area of 3.06 ha (7.55 ac), 10.4 percent of the total watershed.

Each drainage group has an associated runoff value at which rate the subwatershed supplies runoff to the wetland.

Table 1 tabulates the amount of impermeable surface area in each drainage group. Drainage Group I has the least amount of impermeable area, 3 percent, and Drainage Group IV has the greatest percent impermeable area with 55 percent. Approximately 26 percent of the total wetland watershed has impermeable surfaces, either in private drives, roof tops, highways or shopping centers.

TABLE 1. WATERSHED CHARACTERISTICS - IMPERMEABLE AREA

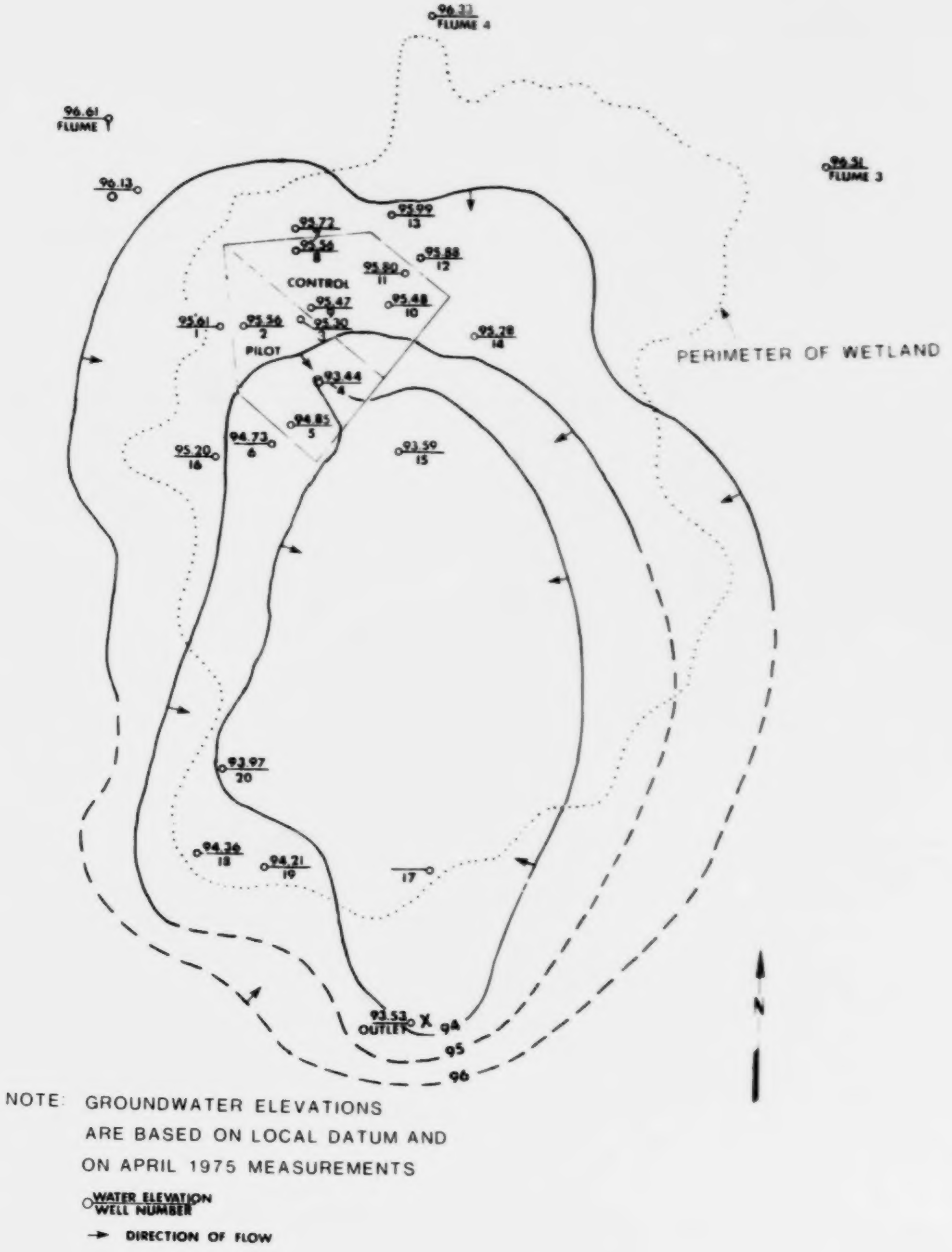
Drainage Group	Sub-Watershed	Total Area ha	Impermeable Area ha	Percent Impermeable
I	1,2,5&7	8.57	0.26	3
II	3,4&11	5.03	0.83	17
III	6,8&9	4.66	2.03	43
IV	10&12	8.05	4.40	55
V	13	3.06	0	0
	TOTAL	29.37	7.52	AVERAGE 26

GROUNDWATER

In the vast majority of wetlands, groundwater is the most important physical and chemical factor of a particular wetland ecosystem. It will be illustrated later in this report that the local groundwater table is in intimate contact with the Wayzata wetland.

The groundwater regime for the Lake Minnetonka area and the wetland specifically is very complex in that the lake and surrounding wetlands are hydraulically connected to the glacial till aquifer. The groundwater gradient in the glacial drift of the wetland watershed is toward the wetland, consequently, the wetland is a point of groundwater discharge. See Figure 8, Groundwater Contour Map.

The glacial till aquifer is also a source of a limited amount of groundwater recharge for underlying artesian aquifers. It has been estimated that vertical permeability of the glacial till is in the order of $4.0 \times (10)^{-7}$ to $3.6 \times (10)^{-6}$ cm/sec (0.01 to 0.08 gpd/sq ft) with an average value in the order of $1.3 \times (10)^{-6}$ cm/sec (0.03 gpd/sq ft) (2). See Figure 9, Hydrologic Cycle.


96.33
FLUME 4
96.61
FLUME 1
96.51
FLUME 3
96.13
0
95.99
13
95.72
7
95.56
8
95.88
12
95.80
11
CONTROL
95.47
9
95.48
10
95.61
1
95.56
2
95.30
3
PILOT
95.28
14
PERIMETER OF WETLAND
93.44
4
94.85
5
94.73
6
95.20
16
93.59
15
93.97
20
94.36
18
94.21
19
17
93.53
OUTLET
X
94
95
96
N
WATER ELEVATION
WELL NUMBER
DIRECTION OF FLOW

NOTE: GROUNDWATER ELEVATIONS
ARE BASED ON LOCAL DATUM AND
ON APRIL 1975 MEASUREMENTS

Figure 8. Groundwater Contour Map

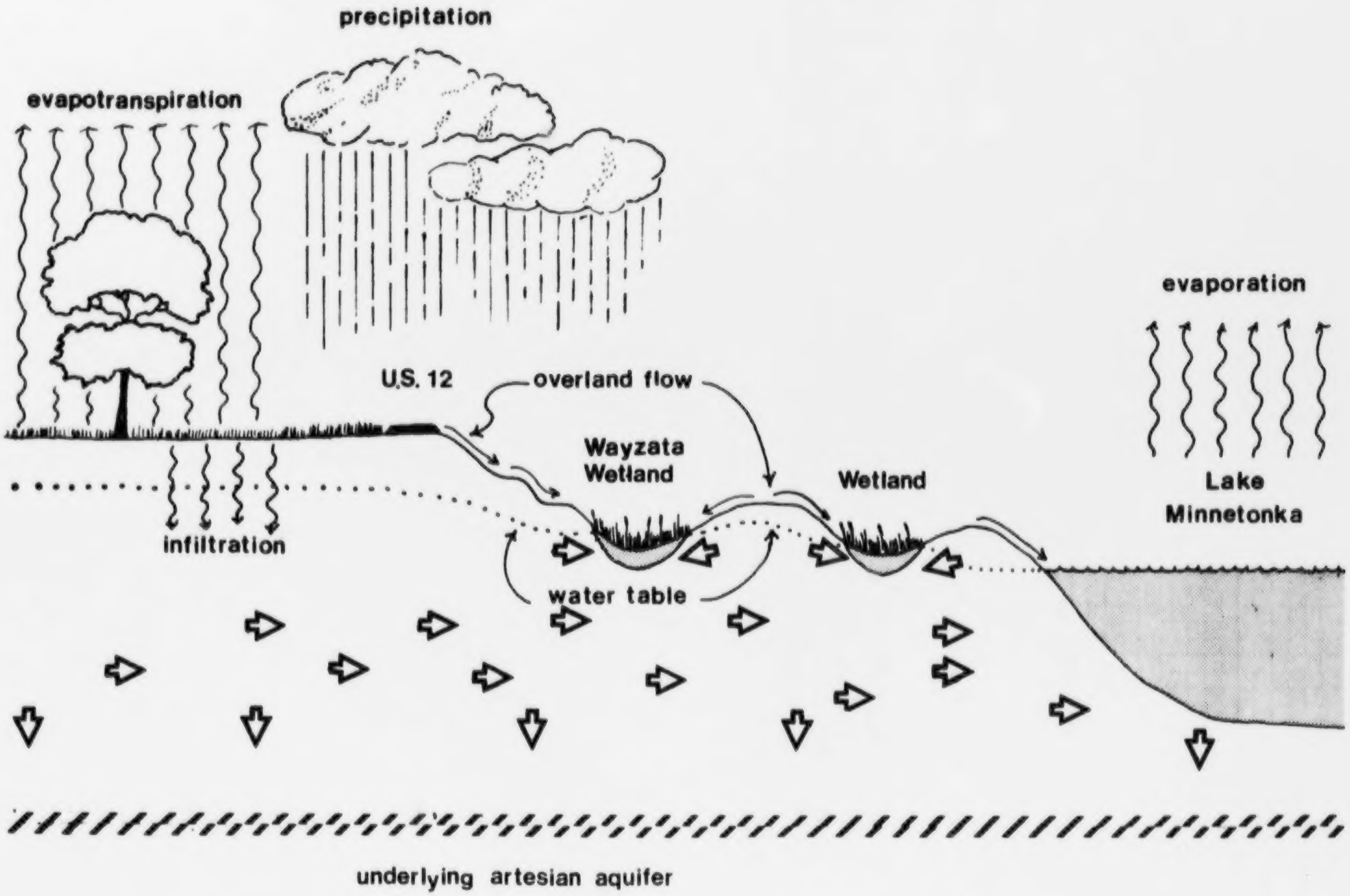

precipitation
evapotranspiration
evaporation
U.S. 12
overland flow
Wayzata
Wetland
Wetland
Lake
Minnetonka
infiltration
water table
underlying artesian aquifer

Figure 9. Hydrologic Cycle

CLIMATOLOGY

The study area is close to the geographical center of the continent; thus, the climate is predominantly the continental type characterized by generally mild subhumid summers and relatively long, severe winters. All climate features tend to extremes. Temperatures ranged from -36°C (-34°F) in January, 1936 and January, 1970 to 42°C (108°F) in July, 1936. Monthly precipitation ranged from a trace in December, 1943 to 20.4 cm (8.03 in) in May, 1962. Abrupt changes in temperature and precipitation are common and are caused by the pressure systems that cross from west to east. Because relief is low, topographic influence on climate patterns is insignificant. Rainfall is greatest during the summer, when it is most favorable for vegetative growth. The average growing season is 166 days. About 55 percent of the annual precipitation is during the period May through August.

The seasonal areal distribution of precipitation is shown in Figure 10, Monthly Precipitation Distribution Minneapolis - St. Paul Area (1936-1975). The annual precipitation over the wetland watershed area was computed to be 72 cm (28.3 in) during the study period.

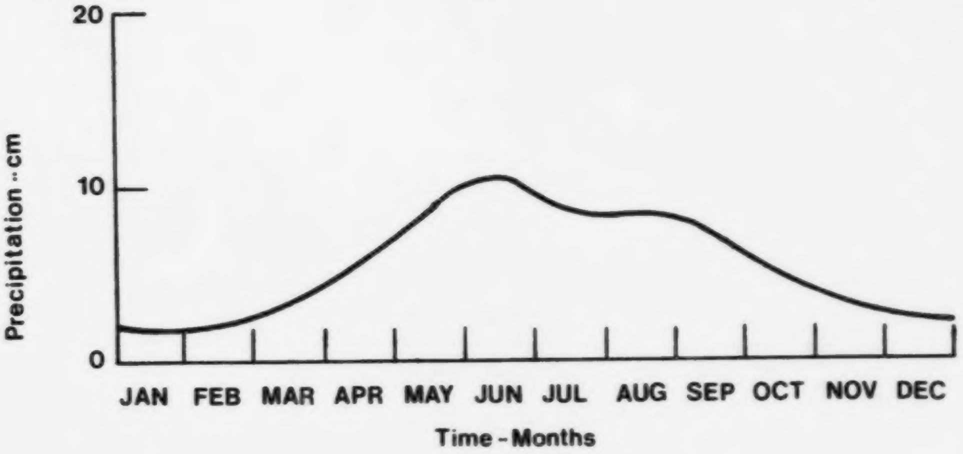


Figure 10. Monthly Precipitation Distribution Minneapolis-St. Paul Area (1936-1975)

Evapotranspiration is highly dependent on climatic events and is an important factor in the water resources of an area. The United States Geological Survey utilized two methods to obtain evapotranspiration values for use in a water budget for the metropolitan area. Two methods were used, the Thornthwaite and Manther method (3) and the energy balance (4).

The average annual evapotranspiration calculated for the area was approximately 57.15 cm/yr (22.5 in/yr); the potential evapotranspiration was approximately 62.23 cm/yr (24.5 in/yr).

The energy-balance method for determining evapotranspiration yields a value of 57.15 cm/yr (22.5 in/yr) of evapotranspiration.

Because these values represent a substantial portion of the total water budget, a complete climatological station was installed in the marsh in order to determine if the micro-climate of the marsh ecosystem was of the same order of magnitude as the previously calculated volumes. The results of this climatological station will be discussed in detail in the section on water balance.

SECTION 6

SITE DEVELOPMENT AND INSTRUMENTATION

Site development and instrumentation centered around obtaining quantitative data to establish the characteristics of runoff and to construct a detailed nutrient and hydrologic balance for the wetland ecosystem.

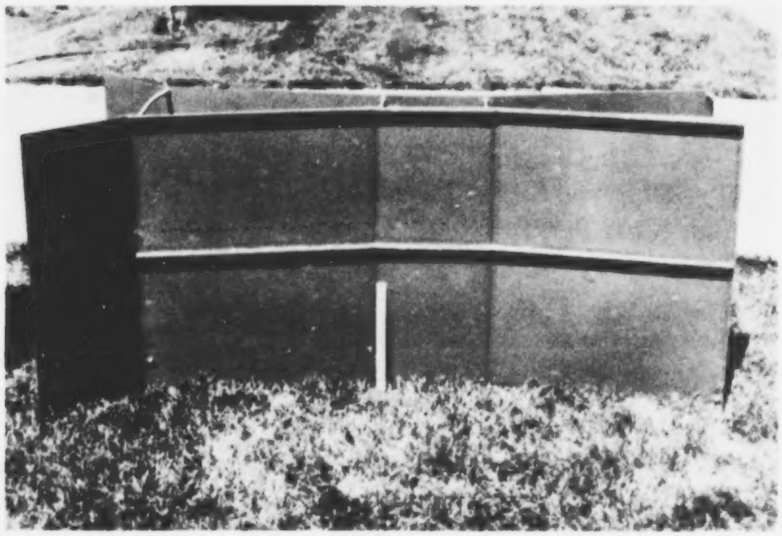
The second aspect of site development and instrumentation was to determine the effectiveness of the wetland management area.

TRIBUTARY WATERSHED

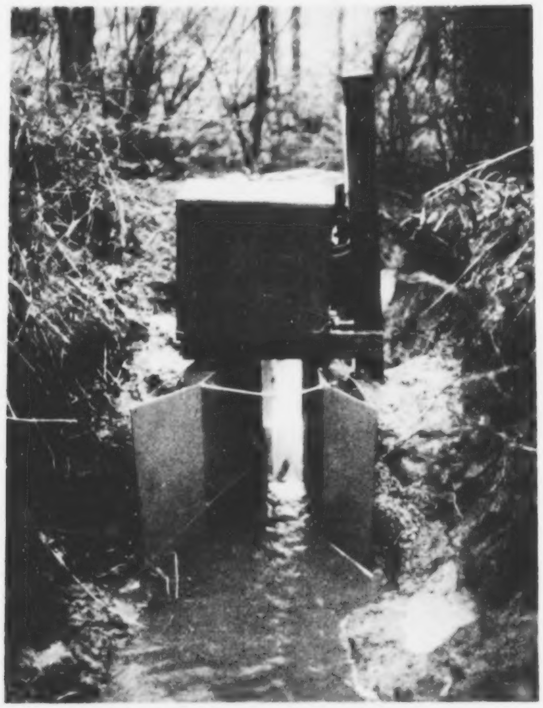
A total of five 15.2 cm (6 in) parshall flumes were installed in the watershed. Four flumes were installed in representative drainage systems that flow into the wetland. The parshall flumes were capable of gaging the flow from as low as 0.063 l/sec (1 gpm) to as high as 12.6 l/sec (200 gpm) and is shown in Figure 11, Instrumentation of Watershed. The fifth flume was installed at the outlet. Each of the inlet flumes were equipped with automatic samplers and flow recorders so as to record as many runoff events as possible. Preceding each flume was a roughing filter of coarse gravel utilized to remove coarse sediment from the runoff.

For pre-selected runoff events, the inlet flumes were equipped with automatic water quality samplers set to sample every 15 minutes with a one hour composite and a 28-hour capacity. A total of 33 runoff events were monitored. A flume was installed at the outlet of the wetland area and was equipped with a continuous water level recorder.

Sixteen 3.5 cm (1.4 in) outside diameter polyvinylchloride observation wells were installed in the wetland area and ten observation wells were installed in the upland areas around the wetland. A typical observation well is shown on Figure 11. The depth of well installation varied between 1.2 m (3.9 ft) and 5.5 m (18 ft) below land surface. The wells were sealed with sheet plastic at the soil surface to prevent surface seepage from entering the well. See Figure 12, Instrumentation of Wetland, for location of the observation wells within

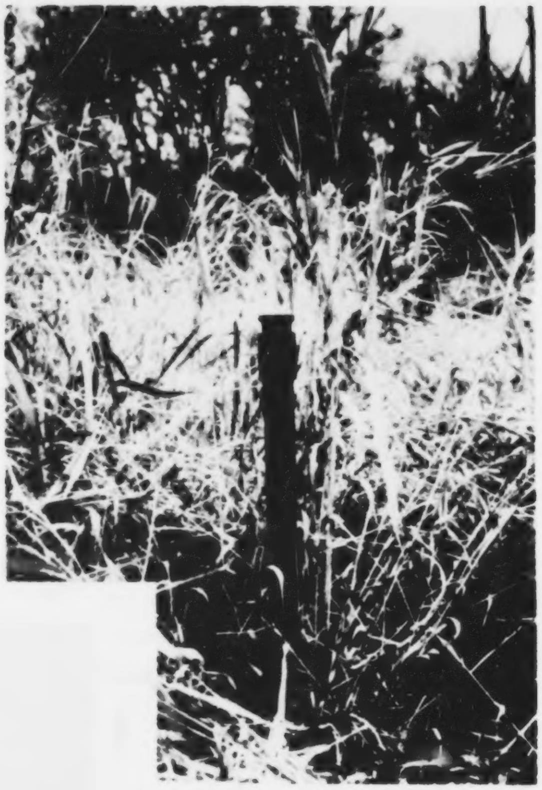


a. Inlet Flume - Drainage Group II

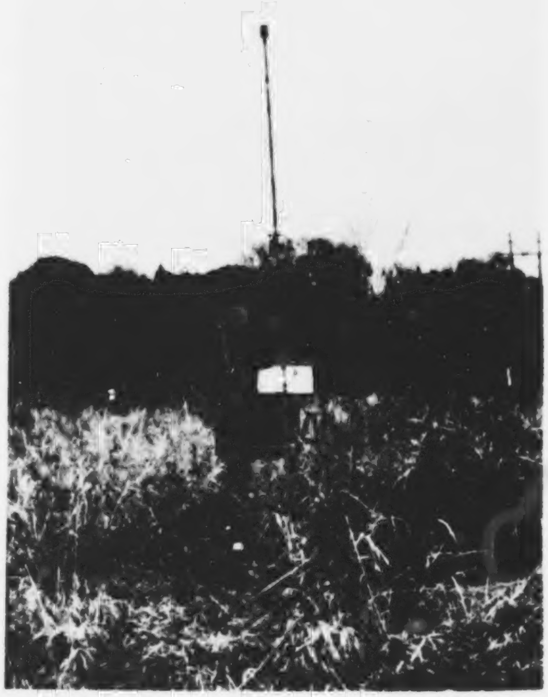


b. Typical Flume

Figure 11. Instrumentation of Watershed



c. Observation Well 14



d. Wetland Weather Station

Figure 11. Continued

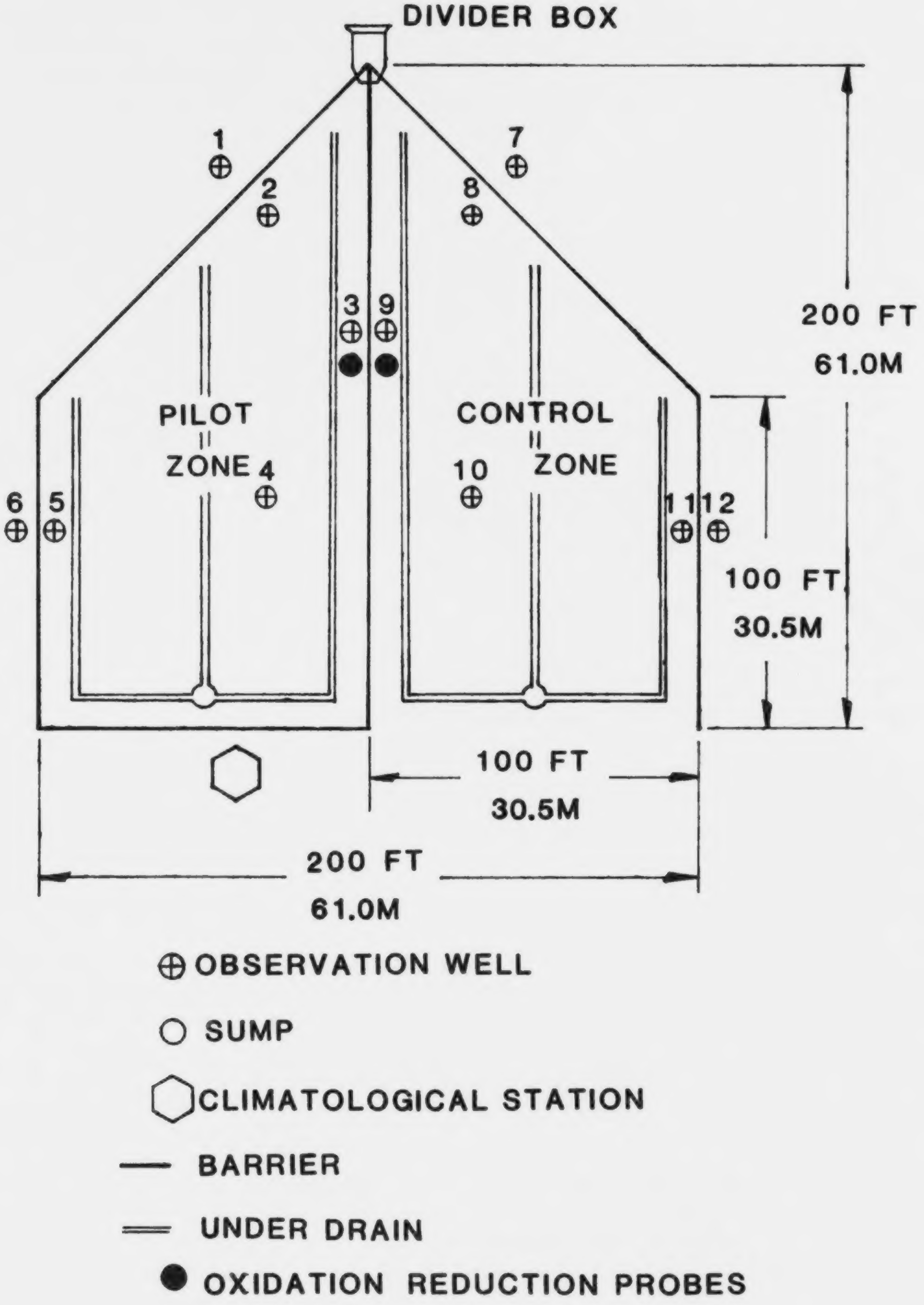

DIVIDER BOX
1
2
7
8
3
9
PILOT ZONE
CONTROL ZONE
4
10
6
5
11
12
200 FT
61.0M
100 FT
30.5M
100 FT
30.5M
200 FT
61.0M
⊕ OBSERVATION WELL
○ SUMP
⬡ CLIMATOLOGICAL STATION
— BARRIER
═ UNDER DRAIN
● OXIDATION REDUCTION PROBES

Figure 12. Instrumentation of Wetland

the wetland area.

A complete weather station was installed in the wetland at the transition of grasses to cattails and sedges to measure all climatological parameters. Recording instrumentation included: temperature-humidity recorder, precipitation gage, two U.S. Weather Bureau evaporation pans and two anemometers. See Figure 11.

Research indicates little is known about the micro-climate of wetlands. The dense vegetation shades the underlying soil and stifles the wind. The wetland is located in a depression near Lake Minnetonka, a 5,700 ha (14,000 ac) water body. These are important factors in determining evapotranspiration rates in wetlands.

A unique climatological monitoring system was installed utilizing two evaporation pans, one in the wetland and one in the adjacent uplands. The wetland pan was installed in such a manner that the bottom of the pan was always in contact with the water table so that the temperature of the water in the evaporation pan would approximate the wetland soil water temperature. Two anemometers were installed at this site. A critical low speed anemometer was placed at a height of 0.5 m (1.6 ft) and a second anemometer at a height of 5.5 m (18 ft) above the wetland soil surface.

Temperature and relative humidity recording devices were also installed near the wetland evaporation pan.

The second evaporation pan was installed in a typical U.S. Weather Bureau fashion in the uplands. A time driven automatic precipitation recorder was maintained in the upland site and precipitation was recorded in the wetland evaporation pan.

WETLAND MANAGEMENT AREA

The perimeter of the Wayzata wetland is subject to aerobic states as the water level drops below soil surface between runoff events and therefore suitable for the control of water levels. Two inlets supply runoff to this area. This area is sufficiently isolated so that slight modifications only were needed to establish a controlled surface water system which could be closely monitored.

Approximately one acre was designated as the study area. A pentagon configuration was chosen for the study area to conform with the natural geography of the area. The area was surveyed to establish water flow boundaries.

Half of the area was designated the pilot zone to be used in the dewatering study, the other half to be used as a control zone. Water tables, soils and vegetation of the two areas are similar.

The study area was subdivided into twelve stations to obtain more detailed observations of the water table and soil activity. Eight stations each were designated for the control and the pilot area. Four stations were located immediately outside the perimeter of the study area to monitor the effects of the water management process on the area outside. Figure 12 shows the layout of the control and monitoring instrumentation.

Oxidation-reduction potentials were determined by installing five electrodes at 15 cm (0.5 ft) intervals at a depth of 2.5 m (8.2 ft) below the soil surface in the pilot station 3 and control station 9.

Chambers to monitor carbon dioxide generated by the soil bacteria were installed at twelve stations within the study area. In situ chambers were constructed from 3.8 l (1 gal) glass jars with the bottoms removed. The jars were inserted 5 cm (2 in) into the soil. Surface vegetation was removed from within the chambers to minimize the influence of carbon dioxide assimilation by plants.

MODIFICATIONS

A system suitable for the programming of controlled water levels was installed within the wetland. All construction was performed manually so as to minimize the impact on the natural wetland. Identical systems and methods were used to prepare the control and the pilot zone.

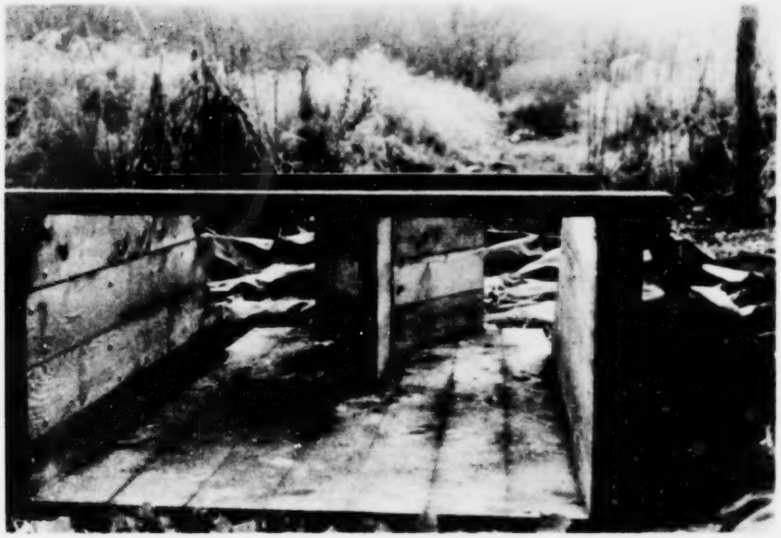
The modifications included:

1. A polyethylene barrier was used to line the channels from the parshall flumes to the wetland perimeter to prevent water penetration into the ground so that all recorded water volumes would enter the wetland as surface water.

2. A polyethylene barrier was buried to a depth of 91 cm (3 ft) surrounding the perimeter of the control and pilot zone to prevent seepage from surrounding groundwater.

3. A divider box constructed of untreated redwood was installed at the junction of the inlet with the wetland to equally split water volumes to the control and pilot zone or to direct the water flow as desired. See Figure 13, Photographs of Instrumentation of Wetland.

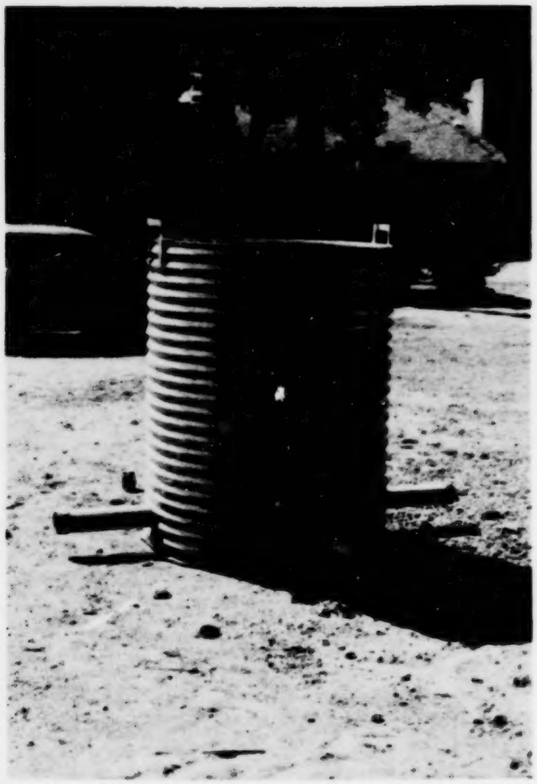
4. An underdrain system of perforated plastic tiles was installed 91 cm (3 ft) below the soil surface to



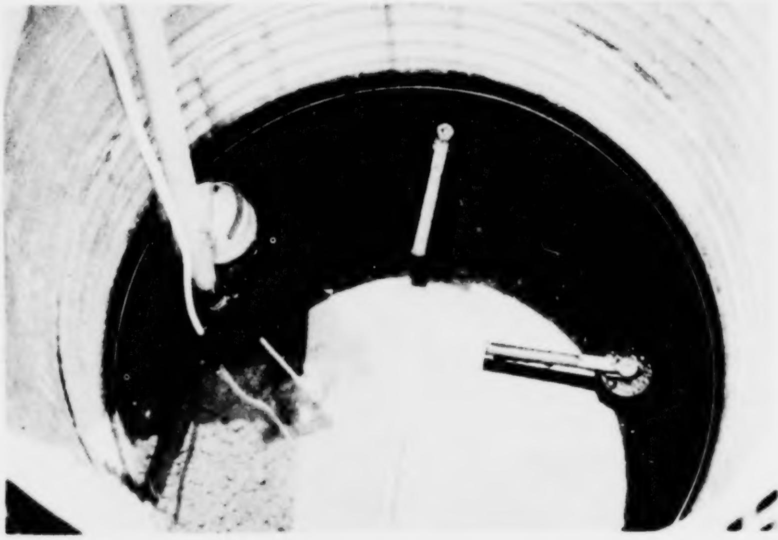
a. Divider box

b. Perforated Plastic Underdrain

Figure 13. Photographs of Instrumentation of Wetland



c. Sump



d. Sump Installed

Figure 13. Continued

direct water to the control sump.

5. A sump constructed of 122 cm (48 in) corrugated pipe, 152 cm (5 ft) deep with a sealed bottom was placed vertically in the ground to which the drain tiles were connected through control valves. See Figure 13.

6. An electrical sump pump was installed in the sump to pump water out of the dewatered area to a peripheral wetland area. See Figure 13.

SECTION 7

METHODOLOGY

MONITORING

Overview

Sampling and analysis was performed periodically to determine the water quality in various parts of the wetland system from November, 1974 to October, 1975. The frequency of sampling and analytical parameters were determined from preliminary sampling. Water quality and volumes were monitored for all water flowing into the wetland, out of the wetland as well as the groundwater within and around the wetland. Precipitation, evaporation, temperature, relative humidity and wind were monitored during the study period.

An intensive evaluation of the soil activity and soil environment in the wetland was performed for a six month period, June, 1975 through November, 1975. Parameters used to evaluate the soil activity included direct counts of soil bacteria and measurement of the generation of carbon dioxide by the soil bacteria.

Special emphasis was placed on data collection during the summer months of June, July and August, 1975, when the wetland system is most active, and the sampling frequency was increased during this period. The following paragraphs describe the monitoring which took place during the project.

Surface Water Quality

Discrete and flow composited samples of four wetland inlets during runoff events were collected and analyzed for total coliform, total suspended solids, ammonia nitrogen, total phosphorus, biochemical oxygen demand and oxidation reduction potential (list A). A total of 130 runoff samples were collected from 17 separate runoff events during the year November, 1974 - October, 1975. Selected composite samples of the runoff were analyzed for iron, copper, lead, zinc and nickel (list B).

Samples of the discharge from the wetland were collected and analyzed for the parameters in list A, November through freeze-up on December 7, 1974 on a daily basis. Daily sampling was resumed April 7, 1975, spring thaw, and continued until June 12, 1975. Six-hour composite samples were taken from June 12, 1975 through June 27, 1976 and twice daily (morning and afternoon) samples were collected from July through October, 1975. Weekly composite samples from the wetland discharge were analyzed for the list B parameters from April, 1975 to October, 1975.

Samples were collected from the sump of the pilot zone on an hourly basis from June 16 through July 12, 1975 (dewatering cycle I) and analyzed for the list A parameters. During (dewatering cycle II) July, 1975 through November, 1975 two samples were collected daily and were analyzed for the list A parameters. Weekly composite samples from the sump were analyzed for the list B parameters from June 16, 1975 through October, 1975.

Surface Water Quantity

Flows were recorded at the wetland inlets during 19 separate runoff events from May, 1975 to September, 1975.

Flow from the wetland outlet was recorded on a daily basis during November and December, 1974 and April and May, 1975. The flow was recorded continuously from June, 1975 to October, 1975.

The electrical consumption of the sump pumping system was recorded on a daily basis during the month of July, 1975 to determine the volume pumped during the dewatering process.

Groundwater

The observation wells in the pilot and control zones were sampled and analyzed for the list A parameters 18 times. The observation wells were sampled monthly from November, 1974 through April, 1975, twice per month during May and June, 1975 and weekly during July and August, 1975.

Groundwater levels were measured at the observation wells in the pilot and control zones twice a month from November, 1974 to June, 1975, daily during June, 1975 and three times a week from July, 1975 to August 13, 1975. The groundwater level of the peripheral observation wells was measured during July and August, 1975.

Soil Activity and Environment

Carbon dioxide generation was monitored at 12 stations four days per week by 24-hour periods from June, 1975 to September, 1975. During October and November, 1975 carbon dioxide generation was measured twice a week.

Weekly, carbon dioxide generation was measured by 72-hour periods from July, 1975 to September, 1975.

Soil bacteria counts of surface soil samples were performed weekly from June, 1975 to mid-September, 1975. Two soil bacteria counts were performed per month from mid-September, 1975 to October, 1975. Each of 15 stations was monitored 20 times.

Soil bacteria counts of subsurface soils were performed at stations 4, 5, 6 and 10 from June 16, 1975 to September 11, 1975 on a weekly basis.

Soil temperatures were monitored at 12 stations on a daily basis from July 7 to July 18, 1975. Twice per week soil temperatures were measured during the period from July 21, 1975 to September 25, 1975. During October and November, 1975 soil temperatures were recorded weekly.

Oxidation reduction potential of soils was monitored for stations 3 and 9 (see Figure 12) at five depths from July 7 to July 21, 1975 on a daily basis. During the period from July 23 to August 13, 1975 the oxidation reduction potential was recorded three times per week.

Other Measurements

Precipitation, air temperature, relative humidity and wind velocity data were recorded continuously from November, 1974 to October, 1975.

Pan evaporation data was continuously recorded from June, 1975 to October, 1975. Daily manual measurements were also taken during July and August, 1975.

SECTION 8

RESULTS

IDENTIFICATION AND CHARACTERIZATION OF THE WATERSHED

The identification and characterization of the watershed can best be analyzed in three separate but related categories, the hydrologic or water balance, the nutrient balance and the resulting impacts on the wetland.

Water Balance

The water balance of the ecosystem consists of the following parameters:

Water Inflows (Gains)

A_i = Precipitation directly on wetland
B_i = Runoff from the tributary watershed
C_i = Groundwater inflow

Water Outflow (Losses)

A_o = Evapotranspiration (transpiration and evaporation) from the wetland
B_o = Discharge at outlet of the wetland
C_o = Groundwater seepage

If the above terms are arranged in the following equation, the change in storage (ΔS) of water in the wetland can be described:

$$\{A_i + B_i + C_i\} - \{A_o + B_o + C_o\} = \Delta S \text{ ..... Eq. 1}$$

It can be stated that the value for ΔS will approximate zero because the water level in the wetland was the same at the end of the study as at the start.

It must be pointed out that the long term ΔS for a particular wetland ecosystem will not be at equilibrium because research has shown that a wetland in the region accumulates organic matter at a rate of approximately 1 cm (0.4 in) per year (7), although the literature states a wide range of values

TABLE 2. PRECIPITATION, NOVEMBER 1, 1974 - OCTOBER 31, 1975, centimeters

	1974		1975									
Day	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1	0.25								5.59	5.72		
2			T								1.02	
3		T	1.07				0.25			0.64		
4	T	T						1.14			0.30	
5				0.69			0.20		0.89	0.25		
6			0.25								0.38	
7							1.27					
8			T			0.05						
9	0.58		0.46			0.13		0.18	0.89		0.38	0.36
10	0.23		2.03			0.25		0.46				
11	T		0.94		0.10			3.61				
12	T				0.51			T				
13	T	0.08					0.25		0.10			
14	T	0.05		0.38				T				
15		0.23				T		2.54				
16		0.10	0.05					0.05		0.3		
17		T				1.57		2.92		0.10		
18	T	0.33	0.46					0.08	T		0.64	
19	0.05	0.08				0.13	0.51				0.10	
20		T			0.13		1.02	2.29		1.65	0.33	
21		T						0.25		0.20	0.25	
22		T				5.84				T		0.05
23	0.25				1.02		1.40		0.25	2.23		0.38
24		0.03			0.51							
25		T	0.25	0.38	T		5.33		0.51	0.13		
26	0.30				T			2.67				
27	T				T	5.33						
28	T			0.38	0.48					1.02	0.15	
29	T		1.02				0.30	0.13		0.10		
30	T											
31					T							
Total	1.66	0.90	6.53	1.83	2.75	13.30	10.53	16.32	8.23	12.34	3.55	0.79

Total 78.73 centimeters (31.00 inches)

(8, 9, 10). Assuming that the organic soil contains 80 percent moisture it can be seen that the system will not be at equilibrium but will actually be storing water.

The three water inputs to the wetland are direct precipitation, runoff and groundwater inflow and will be discussed in the following paragraphs.

Direct Precipitation--

During the period from November 1, 1974 to October 31, 1975 a total of 77.7 cm (30.6 in) of precipitation fell directly on the wetland as shown on Table 2. This is 5.8 cm (2.3 in) above the 31 year normal. Of the total precipitation, 78 percent fell during the period April through August.

The precipitation falling directly on the wetland, 3.06 ha (7.55 ac) contributed a total of 2.38 ha-m (19.3 ac-ft) of water to the water balance.

Runoff--

The average runoff coefficient for the entire watershed tributary to the wetland was 0.156.

The runoff coefficients ranged from 0.071 for Group I to a high of 0.32 for Group IV. See Figure 5 for the location of each drainage group and also Table 3 for areas and average runoff coefficients.

TABLE 3. RUNOFF COEFFICIENTS

Drainage Group	Area ha	Area ac	Percent of Tributary Watershed	Runoff Coefficient
I	8.57	21.17	33	0.07
II	5.03	12.44	19	0.09
III	4.66	11.52	18	0.09
IV	8.05	19.88	31	0.32

Average for total tributary watershed - 0.156

Utilizing these general coefficients of runoff, a total of 3.19 ha-m (25.9 ac-ft) of water was added to the wetland water balance equation via surface runoff.

Groundwater Inflow--

The groundwater inflow into the wetland comes from basin storage and remains relatively constant.

In order to determine the groundwater contribution to the wetland area a flow net analysis was conducted using the following equation:

$Q = KiA$ ..... Eq. 2

Q = Flow, l/day (gpd)
K = Coefficient of permeability cm/sec (gpd/ft^2)
i = Hydraulic gradient
A = Cross sectional area through which flow occurs

Permeability tests were conducted on two representative groundwater monitoring wells. The results of these tests indicate that permeability of till was in the order of 5×10^{-4} cm/sec (10.64 gpd/ft^2).

A review of the groundwater levels recorded at the monitoring locations during the study period illustrates that the groundwater gradient tributary to the wetland remained relatively stable at approximately one percent. See Figure 8 , page 22.

Using these values in equation 2, the average daily groundwater contribution to the wetland is approximately 0.38 - 0.50 l/sec (6-8 gpm) or 1.20 ha-m (9.7 ac-ft) annually.

The permeability of the organic soils was not considered as a factor in the groundwater contribution because much of the organic soils consisted of very fibrous peat which was extremely permeable typical to those values reported by Boelter (11).

Using a method developed by Kunkle (12) it is possible to separate basin storage discharge or groundwater inflow from the annual hydrograph. Two assumptions are made in constructing the line separating basin-storage discharge from the other runoff components. First, the minimum discharge values at the beginning and end of the groundwater year are assumed to represent groundwater discharge from basin storage. This assumption is based on the premise that at the beginning and end of the groundwater year, groundwater storage is at a minimum. Therefore, bank storage has been depleted and, provided that there has been no recent precipitation, all the discharge is coming from basin storage. The second assumption is that groundwater discharge from basin storage varies only to a minor extent throughout the groundwater year and that fluctuations tend to cancel one another.

The second assumption is most valid for the typical groundwater year. During a typical groundwater year the amount of discharge is closely balanced by an equal amount of recharge. This phenomenon is observed when the minimum discharge values at the beginning and end of the groundwater year are very nearly equal. This fact is also exhibited by the relatively constant groundwater gradient in the till tributary to the wetland.

Figure 14, Hydrograph - Wetland Discharge, illustrates the daily discharge plotted on a semi-logarithmic scale. This illustration was used to evaluate the groundwater inflow and wetland responsiveness to precipitation.

The dashed line connecting the low flow at each end of the study period represents the groundwater discharge into the wetland. This value is approximately 0.38 l/sec (6 gpm) or 1.19 ha-m (9.7 ac-ft) annually and agrees well with the groundwater contribution calculated from the flow net analysis.

The study period, November 1, 1974 - October 31, 1975, was chosen because it represented a groundwater year as illustrated by Figure 14. During November, 1974, September, 1975 and October, 1975 the discharge from the wetland stabilized at approximately 0.38 l/sec (6 gpm).

In summary the total water inputs to the wetland ecosystem water budget for the groundwater year is as follows:

Precipitation	2.38 ha-m	19.3 ac-ft
Surface Runoff	3.19 ha-m	25.9 ac-ft
Groundwater Inflow	1.20 ha-m	9.7 ac-ft
	6.77 ha-m	54.9 ac-ft

Therefore, the total water input equalled approximately 6.77 ha-m (54.9 ac-ft) from November 1, 1974 through October 31, 1975.

The second portion of the water balance consists of determining the water losses from the wetland. These losses occur as evapotranspiration, groundwater seepage and discharge from the wetland outlet.

Evapotranspiration Losses--

Since the wetland is located in a depression, it was decided to instrument the watershed with data collection equipment that would provide the necessary input to calculate the evapotranspiration rate using the Penman method (13).

The Penman equation is based on a complete theoretical approach, showing that evapotranspiration is inseparably connected to the amount of radiative energy gained by the surface. See Appendix D for equation.

Results of the wetland evaporation pan were somewhat startling in the fact that the evaporation values during the height of the growing season departed substantially from evaporation

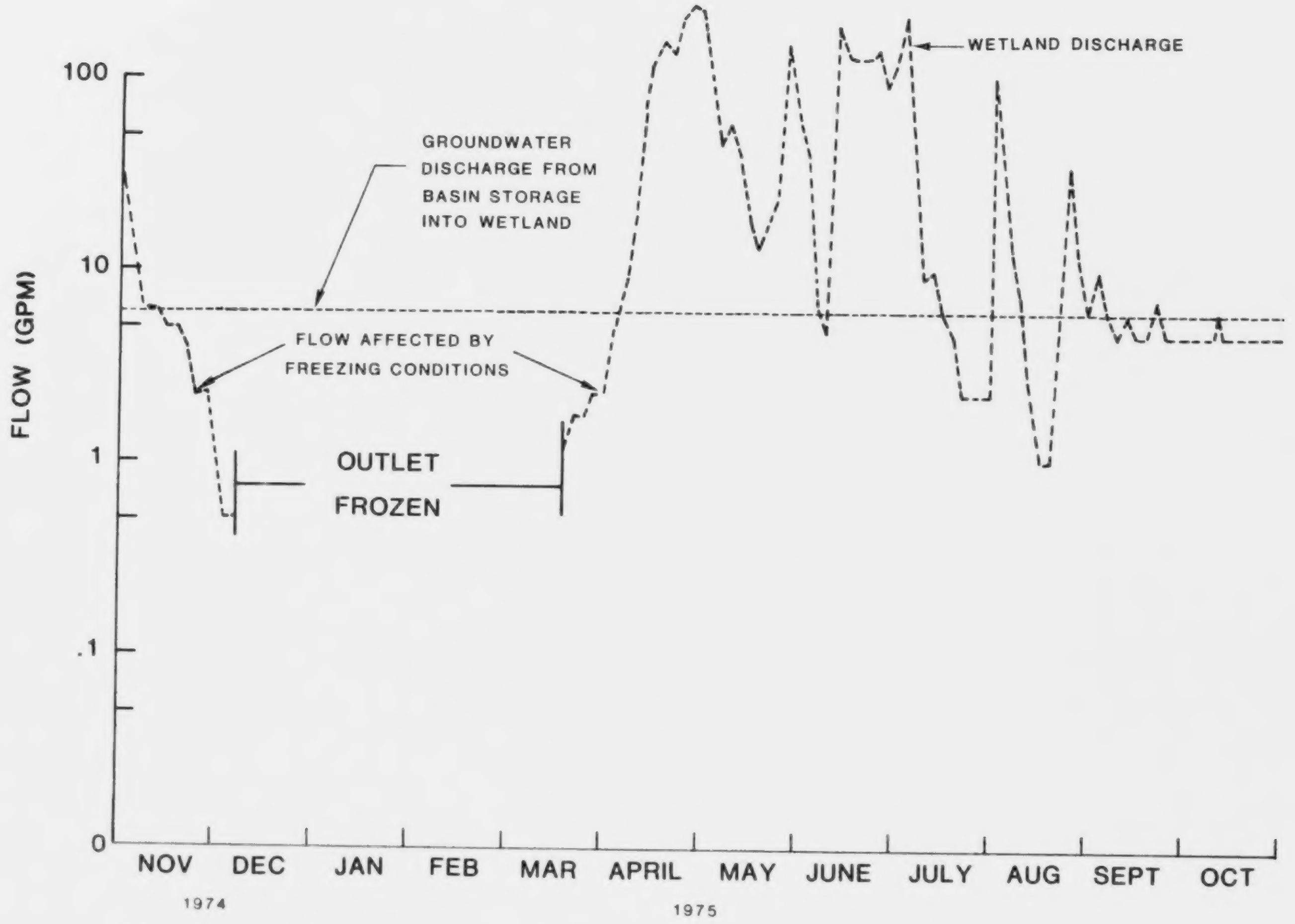


Figure 14. Hydrograph - Wetland Discharge

rates recorded by the University of Minnesota, St. Paul, some 55 km (34 mi) away.

The values recorded during the entire year show little agreement with the exception of a general decline during the season. The University of Minnesota values were substantially higher. Figure 15, Evaporation Pan Data - Wetland vs. University of Minnesota, St. Paul, illustrates the difference in evaporation rates. It is of interest to note that the two stations responded almost the opposite to the wet period during May and June, 1975 with wet periods tending to reduce the University values for this period, whereas the values for the wetland increased. The increase in the rate of evaporation in the wetland may be due to a general warming as a result of the runoff entering the wetland. During the period July to mid-September both stations showed the same response to the climatic conditions. However, a sharp increase in the rate of evaporation was recorded at the University of Minnesota station from mid-September through October, whereas the wetland pan continued to decline. There is no apparent explanation for this difference in response to climatic conditions.

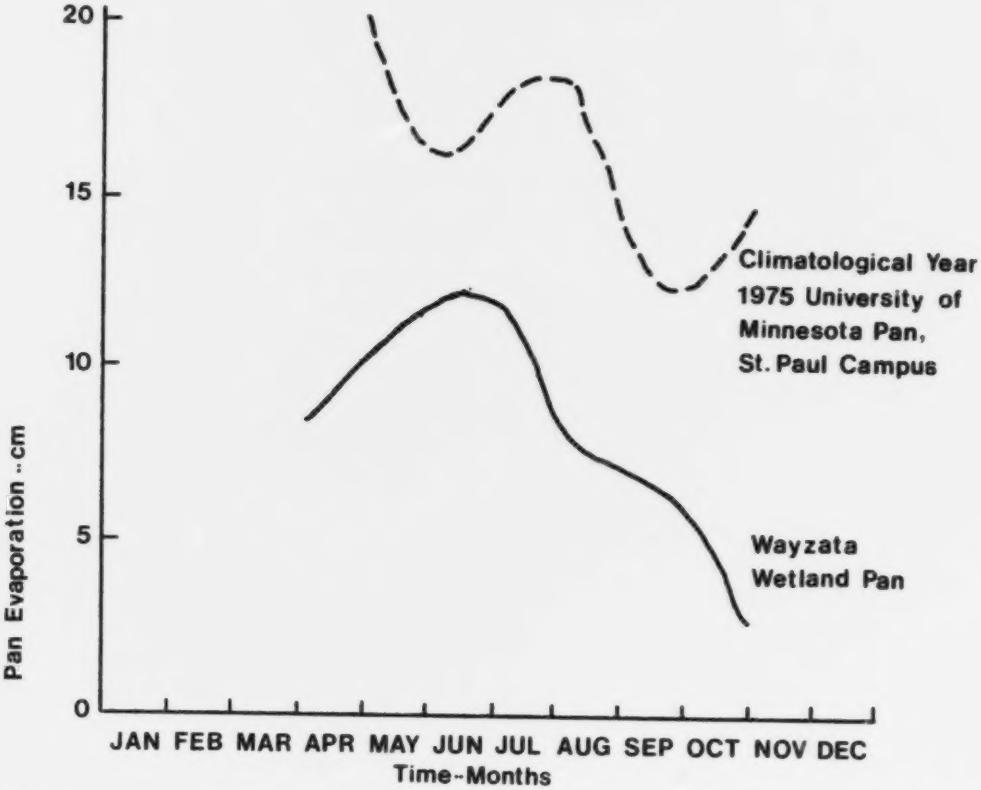


Figure 15. Evaporation Pan Data - Wetland vs. University of Minnesota, St. Paul

The total evaporation from the wetland during the period November 1, 1974 to October 31, 1975 was 64.3 cm (25.3 in). It was not possible to compare this value directly with the University of Minnesota station because many of the months used in this study were not recorded at the University of Minnesota station. At the end of May the vegetation was approximately 30 cm (12 in) in height, consequently, the vegetation probably had less effect on the rate of evaporation; however, as the season progressed, the height of vegetation has an apparent inverse effect on the rate of evaporation from the wetland.

Utilizing the Penman equation (see Appendix D), the calculated rate of evapotranspiration for the wetland was approximately 58.59 cm (23.06 in) during the 1975 growing season. Table 4 gives a complete list of coefficients utilized to calculate the rate of evapotranspiration for the wetland.

TABLE 4. EMPIRICAL COEFFICIENT - PENMAN EQUATION

Time (month)	Radiation (cal/cm^{-1} day^{-2})*	Relative Humidity (percent)	Maximum Possible Sunshine (hours)*	Average Wind Velocity (MPH-18ft)	Average Monthly Temperature (^{O}C)
April	807.5	70.0	13.5	11.2	3.8
May	913.3	60.0	14.9	9.7	15.5
June	997.1	68.9	15.6	8.9	20.4
July	928.4	58.7	15.3	9.0	24.6
Aug.	810.8	66.6	14.1	7.8	22.0
Sept.	663.8	69.8	12.6	8.4	14.3
Oct.	467.1	58.0	11.0	9.4	12.1

*Source: U.S. Weather Bureau - Minneapolis-St. Paul Airport

Table 5 indicates the values of evapotranspiration at the Wayzata wetland. This value agrees with the values (55.9 - 59.4 cm) estimated for the area by the United States Geological Survey. As a result of this work and work by Lawrence (14), it should be pointed out that there is a need for research in this aspect of a wetland water budget. It was apparent to workers in the wetland that noticeable differences in relative humidity existed within the wetland depending upon the type of vegetation present. The wetland area appeared to contain hot spots. These observations were also made by Lawrence. Empirical formulas utilized to calculate the rate of evapotranspiration can vary as much as 100 percent depending upon where and how the data is gathered in a given wetland. Daily pan evaporation values for the wetland indicated stable conditions in that there was little day to day fluctuation. The wetland evaporation appeared to respond more to seasonal warming and cooling. The wetland evaporation pan was in contact with the soil water system and closely approximates the actual role of evaporation.

TABLE 5. EVAPOTRANSPIRATION - WAYZATA WETLAND

Month	Evapotranspiration (centimeters)	Evapotranspiration (inches)
April	5.10	2.01
May	9.78	3.85
June	11.38	4.48
July	14.04	5.53
August	9.17	3.61
September	5.36	2.11
October	3.76	1.48
	58.59	23.07

Given an evapotranspiration rate of 58.59 cm (23.07 in) from a wetland area of 3.06 ha (7.55 ac) a total of 1.79 ha-m (14.52 ac-ft) of water was lost from the wetland through evapotranspiration during the growing season, April 1, 1975 to October, 1975.

Groundwater Losses--

It can be assumed that there are no significant groundwater losses from the wetland because groundwater contour maps prepared from monitoring well data indicate that the wetland area is a point of discharge for the local glacial till. Figure 8, page 22, illustrates the direction of flow. Consequently, the groundwater losses are considered zero in the water balance equation.

Surface Discharge--

A parshall flume with a continuous water level recorder was installed at the outlet of the wetland. A total of 5.44 ha-m/yr (44.17 ac-ft/yr) of water was discharged from the wetland through the outlet. See Table 6 for monthly totals, and Figure 10, page 24, for daily variations in discharge.

It is of interest to note the impact the hot, dry summer had on the discharge for the wetland. As can be seen from Figure 14, page 43, periods during early June, July and August, 1975 the evapotranspiration rate exceeded the groundwater recharge rate consequently reducing the minimum flow to less than the estimated base flow of approximately 0.33 l/sec (6 gpm).

The total water losses from the wetland ecosystem are as follows:

Evapotranspiration (E.T.)	1.79 ha-m	14.52 ac-ft
Discharged at Wetland Outlet	5.44 ha-m	44.17 ac-ft
	7.23 ha-m	58.69 ac-ft

TABLE 6. WETLAND FLOW DISCHARGE

Year	Month	Discharge Hectare-meter (ha-m)	 Acre-feet (ac-ft)
1974	November	0.13	1.06
1974	*December	0.002	0.02
1975	*January	--	--
1975	*February	--	--
1975	*March	0.015	0.12
1975	April	1.69	13.70
1975	May	1.19	9.69
1975	June	1.48	11.98
1975	July	0.43	3.49
1975	August	0.33	2.69
1975	September	0.09	0.75
1975	October	0.08	0.67
		5.437	44.17

*Outlet either completely frozen or frozen for some portion of the above months

Storage--

Utilizing water balance Equation 1, page 38,

Precipitation + Runoff + Groundwater - Outflow = Balance (ΔS)

$$\{2.38 + 3.19 + 1.20\} - \{1.79 + 5.44\} = 0.46 \text{ ha-m}$$

it appears that 0.46 ha-m (3.45 ac-ft) was removed from wetland storage during the study period.

Nutrient Balance

The same basic equation utilized in the water balance is also applicable to use in the nutrient balance.

The following factors are considered part of the wetland nutrient balance.

Nutrient Inflows (Gains)

A_i = Nutrients in the precipitation directly on wetland
B_i = Nutrients in the runoff from tributary watersheds
C_i = Nutrients in the groundwater inflow

Nutrient Outflow (Losses)

A_o = Nutrients in the evapotranspiration from the wetland
B_o = Nutrients in the discharge at the outlet of the wetland
C_o = Nutrients in the groundwater seepage
D_o = Nutrients in materials removed from the wetland

Unlike the water balance, nutrient losses from evapotranspiration and groundwater seepage are not factors in the total nutrient budget. No known nutrients are lost from the wetland as a result of evapotranspiration and no materials were removed from the study wetland. Groundwater discharges to the wetland, therefore, there is no groundwater seepage from the wetland. Consequently, the nutrient balance would be as follows:

$\{A_i + B_i + C_i\} - B_o = \Delta S$ ..... Eq. 3

It is one of the primary objectives of this report to determine the relative value of ΔS. It has been assumed simply because of the accumulation of organic matter that ΔS will show a net gain in nutrients in the wetland. However, the relative magnitude of change in ΔS is the important aspect of the study.

Precipitation--

Research has indicated that precipitation contains small but finite amounts of potential nutrients.

A number of studies (15, 16, 17, 18) indicates that the total phosphorus occurring in precipitation varies between 0.002 mg/l to 0.03 mg/l. With the exception of the data collected by Krupa (18), the above results were obtained from relatively undeveloped areas.

Assuming a mean concentration of 0.03 mg/l for phosphorus, 0.75 mg/l for ammonia nitrogen concentration and 1 mg/l for total suspended solids, the following nutrients were added to the wetland nutrient budget by precipitation:

phosphorus, 0.7 kg/yr (1.6 lbs/yr);
ammonia nitrogen concentration, 17.8 kg/yr (39.3 lbs/yr);
and total suspended solids, 24 kg/yr (52 lbs/yr)

Runoff Quality--

The quality of the runoff water which reaches the wetland from the area tributary is variable, and appears to be a function of land use (impermeable area) and season of the year.

In terms of land use, drainage group II consists of single family, small lots and the highest average concentration of total phosphorus and ammonia nitrogen concentration of the four drainage groups tributary to the wetland area. Whereas drainage group IV, shopping centers, etc. (56 percent impermeable) had the lowest average concentration as shown in Table 7.

TABLE 7. COMPARISON OF STORMWATER RUNOFF QUALITY

Drainage Group	SPRING, 1975 TP mg/l	SPRING, 1975 NH_3-N mg/l	SPRING, 1975 TSS mg/l	SUMMER, 1975 TP mg/l	SUMMER, 1975 NH_3-N mg/l	SUMMER, 1975 TSS mg/l	FALL, 1975 TP mg/l	FALL, 1975 NH_3-N mg/l	FALL, 1975 TSS mg/l
I	2.2	3.33	780	0.37	4.13	1200	0.30	4.33	70
II	2.4	3.87	559	0.73	5.44	3800	0.42	4.97	60
III	2.0	2.85	580	0.22	5.13	374	0.22	4.00	68
IV	1.9	2.55	614	0.09	2.86	200	0.25	3.81	100
Average	2.1	3.15	633	0.35	4.39	1394	0.30	4.28	75

NOTE: Above concentrations are based on weighted values calculated from specific runoff events that occurred during the study period.

TP = Total phosphorus
NH_3-N = Ammonia nitrogen
TSS = Total suspended solids

Because of the weather that was experienced during the winter of 1974-1975, no runoff occurred from December until April, consequently, quality values were not assigned for a winter period but were included in the spring values.

As can be seen from Table 7, a great deal of variation occurs in the quality of runoff water as a result of seasonal ranges. The highest phosphorus values were recorded during the April runoff which included the time period December through May, with the greatest concentration running off with early rains and snow melt. However, as illustrated by Figure 16, Pollutograph of May, 1975 Storm Drainage Group II Subwatershed II, high levels of phosphorus still occurred late in May.

During the summer months, June through August, the level of phosphorus in the runoff dropped substantially. However, the relative position of the various drainage groups in respect to total concentration remained the same with Group II still showing the highest values.

The phosphorus values during the fall months, September through November, generally equalized for all of the drainage groups.

Drainage Group II recorded the highest average concentra-

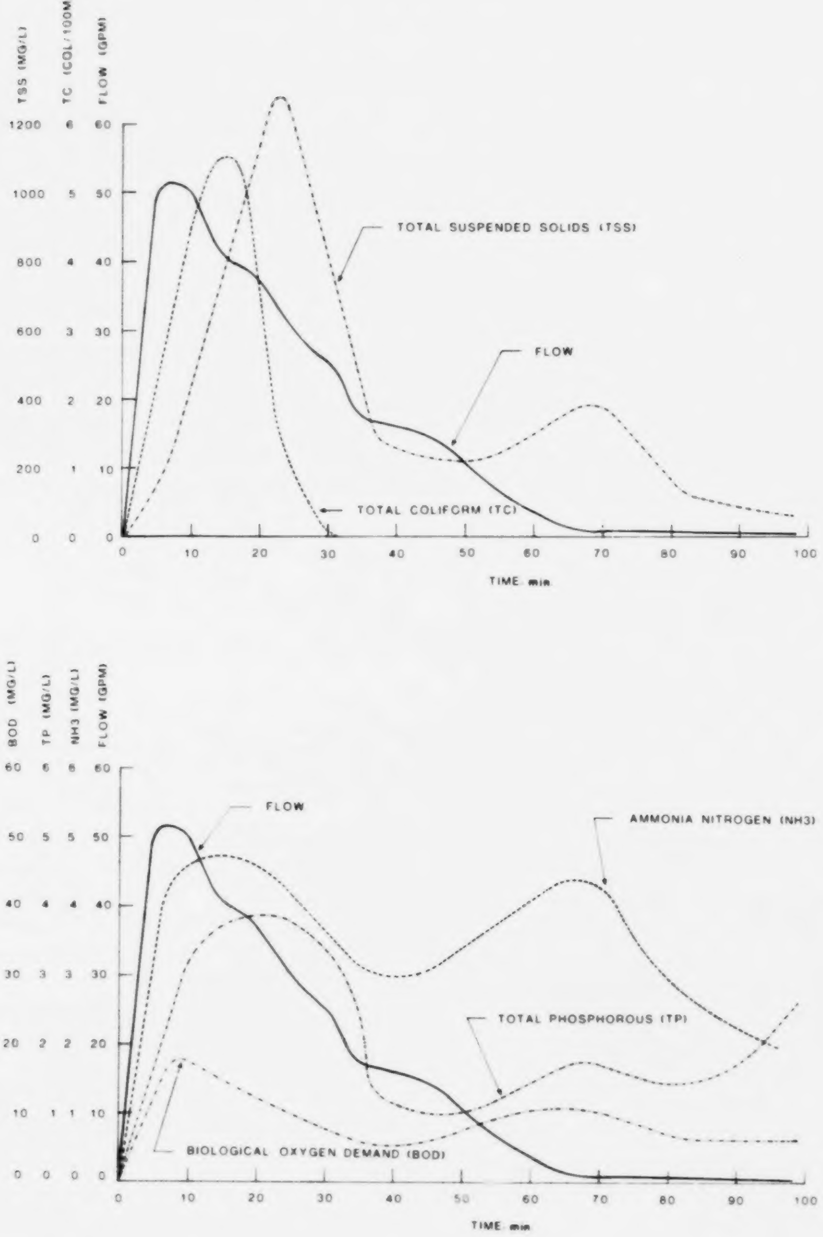


Figure 16. Pollutograph of May, 1975 Storm - Drainage Group II, Subwatershed II

tion for ammonia nitrogen concentration, during the spring season, however, during the summer and fall season, this correlation did not exist.

A comparison of annual quantities of pollutants delivered to the wetland by the various drainage groups is presented in Table 8.

TABLE 8. COMPARISON OF ANNUAL POLLUTANT LOADS

Drainage Group	Total Phosphorus (kg/ha/yr)	Ammonia Nitrogen (kg/ha/yr)	Total Suspended Solids (kg/ha/yr)
I	0.11	0.34	84
II	0.17	0.54	241
III	0.13	0.47	54
IV	0.39	1.13	163
Weighted Average	0.21	0.64	133.8

Drainage Group IV, shopping centers, has the highest annual contribution of nutrients followed by Drainage Groups III, II and I, respectively.

Keup (19) reviewed the sources of phosphorus in flowing water based on the contributing watershed area, and found the areal contribution to vary between 0.001 and 0.026 kg/ha/yr (0.006 and 0.14 lbs/ac/yr). In general, the more densely populated agricultural areas of the Midwest were highest.

The average phosphorus value of the runoff from the study area is 0.21 kg/ha/yr (1.13 lbs/ac/yr). This agrees with the findings by Keup and also results by Sorenson (20). Sorenson's findings indicate that the average annual contribution to French Lake, a drainage area approximately 5.6 km (3.5 mi) west of the project area, was approximately 0.21 kg/ha/yr (1.13 lbs/ac/yr). The French Lake watershed is similar to the Wayzata wetland watershed.

Groundwater Contribution--

As illustrated earlier, the groundwater contribution to the wetland area remained relatively constant during the entire period of investigation. However, the values for phosphorus and ammonia nitrogen concentration were variable.

Groundwater quality tributary to the wetland was established from observation wells located up gradient from the wetland and in mineral soils. See Figure 12, page 29, for location of the observation wells.

The phosphorus values recorded in the observation wells varied from a low of 0.06 mg/l to a high of 18.0 mg/l with an average value of 2.2 mg/l.

As mentioned earlier, the soils that make up the tributary watershed were deposited by the Grantsberg sublobe, a material naturally high in phosphorus.

Routine groundwater sampling of shallow wells in the Lake Minnetonka area commonly encounter wells having phosphorus values in this range (21).

The ammonia nitrogen concentrations in the observation wells varied from 1.9 mg/l to 30.0 mg/l with an average value of 8.3 mg/l.

As a result of those observations it has been calculated that the groundwater inflow supplied 26.6 kg (58.7 lbs) phosphorus and 100.5 kg (221.6 lbs) ammonia to the wetland during the period of study.

Total suspended solids were not determined for the groundwater contribution because the observation well screen (slotted pipe) would not effectively screen the organic soil out during pumping. The normal contribution from this source is low. The total nutrient inflow into the wetland as a result of direct precipitation, stormwater runoff and groundwater discharge for ammonia, phosphorus and total suspended solids is shown in Table 9.

TABLE 9. ANNUAL NUTRIENT INFLOWS

	Phosphorus		Ammonia-N		Total Suspended Solids	
	kg/yr	lbs/yr	kg/yr	lbs/yr	kg/yr	lbs/yr
Precipitation	0.7	1.6	17.8	39.3	24	52
Surface Runoff	33.8	74.6	103.3	227.8	17010	37500
Groundwater	26.6	58.7	100.5	221.6	--	--
Total Inflow	61.1	134.9	221.6	488.7	17034	37552

Nutrient Outflow--

As expressed in the nutrient balance equation, the only means by which nutrients leave the wetland is in the discharge water passing through the outlet.

Discharge flows were recorded and water quality sampling and analyses were performed. Nutrient quantities have been determined from composite samples as shown in Table 10.

TABLE 10. DISCHARGE QUANTITIES FROM WAYZATA WETLAND NOVEMBER, 1974 - OCTOBER, 1975

Month	Phosphorus (kg)	Ammonia Nitrogen (kg)	Total Suspended Solids (kg)	Water (kg$(10)^6$)
NOV	0.29	1.36	36.48	1.31
DEC	0.004	0.04	1.33	0.03
FROZEN				
MAR	0.02	1.00	0.47	0.15
APR	3.28	73.95	209.31	16.84
MAY	2.56	85.47	213.19	11.96
JUN	4.38	103.01	176.90	14.77
JUL	2.09	44.20	240.41	4.30
AUG	0.38	6.91	120.75	3.32
SEP	0.05	2.01	8.48	0.93
OCT	0.14	1.31	17.65	0.82
Total	13.19	319.26	1024.97	54.43

The table illustrates the monthly discharge of phosphorus, ammonia nitrogen concentration and total suspended solids from the Wayzata wetland. The seasonal variations are very similar to those exhibited in runoff quality. Figure 17, Relationship of Wetland Outflow, Ammonia Nitrogen Concentrations and Total Phosphorus Concentrations, shows the relationship to outflow, ammonia nitrogen concentration and total phosphorus to time.

Removal--

Completing the nutrient balance for phosphorus it can be illustrated that for the study year, November, 1974 through October, 1975, 78 percent of all phosphorus entering the wetland was retained in some form. Net gain in wetland is calculated to be 47.9 kg/yr.

The ammonia nitrogen balance indicates that greater quantities of ammonia nitrogen left the wetland than entered the system. Net loss from the wetland would be 97.3 kg/yr.

The results of the ammonia nitrogen values will be discussed in greater detail in the following section, however, it appears that the increased ammonia nitrogen in the discharge water is the result of the transformation of nitrogen compounds.

Completing the balance for total suspended solids shows that 94 percent of the total suspended solids entering the wetland system are retained, i.e., 16,009 kg/yr.

The total suspended solids component of urban stormwater runoff is often the parameter which exceeds effluent limitations,

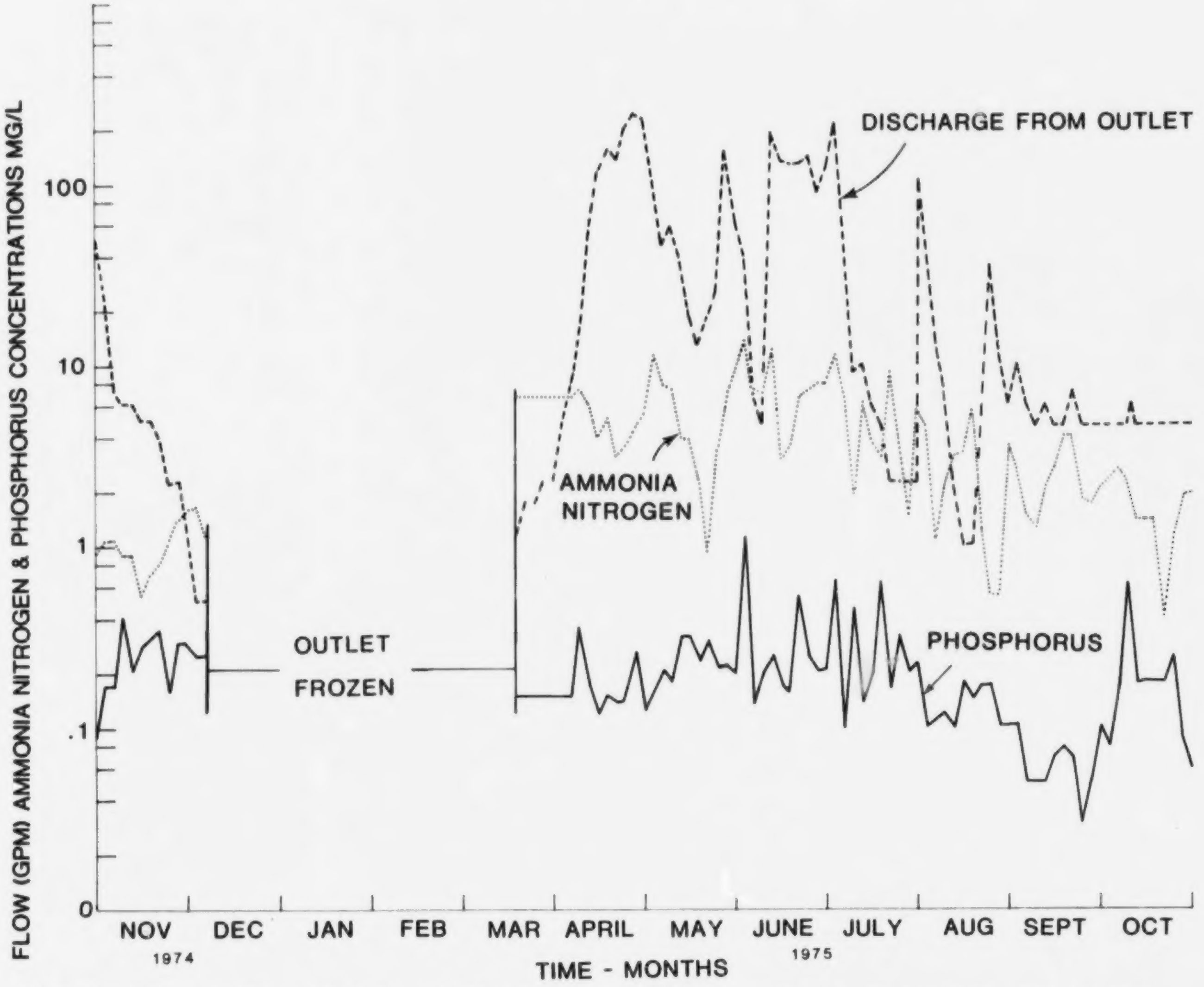


Figure 17. Relationship of Wetland Outflow, Ammonia Nitrogen Concentrations and Total Phosphorus Concentrations

therefore, the removal efficiency is an important aspect of the wetland system.

Heavy Metals--

The average concentrations of heavy metals; zinc, lead, copper and cadmium for the stormwater runoff and the outlet from the wetland are shown in Table 11. The table shows that the runoff from highway and shopping center land use has significantly higher concentrations of all the metals than the undeveloped and large residential land use. The table also shows the average concentrations of the metals in discharge from the wetland. The reduction in concentration of all the metals but cadmium appears significant.

TABLE 11. COMPARISON OF AVERAGE HEAVY METAL CONCENTRATIONS

Drainage Group	Zinc μg/l	Lead μg/l	Copper μg/l	Cadmium μg/l
I - Undeveloped and residential large lots	10	26	12	0.4
II - Single family on small lots	11	26	19	0.9
III & IV - Highway and shopping center	15	71	19	1.4
Wetland Outlet	2.2	2.5	3.3	0.3

Wetland Ecosystem

The interactions of the water and nutrient balances within the wetland ecosystem including water level, water quality, nutrient discharge and microbial activity are discussed in this section.

The Wayzata wetland exists because the rate of deposition of organic matter exceeds the rate of decomposition.

It has been established (7) that the rate of accumulation of organic matter in a wetland at a similar stage of development was approximately 1.3 cm/yr (0.5 in/yr).

It should be recognized that the rate of peat accumulation is not a uniform process but rather depends on many factors, each of which influences the rate and amount of accumulation.

Soper (22) concluded that in the lake states region of the United States, organic deposits which accumulate in ponds or lakes generally go through the following succession stages:

1. Stonewort-waterweed stage (_Chara_-_Philotria_ _associes_),
2. Pondweed-water lily stage (_Potamogenton_-_Nymphaea_

associes),

3. Rush-wild rice stage (*Scirpus-Zizania associes*),
4. Bog-meadow stage (*Carex associes*),
5. Sphagnum-bog heath stage (*Andromeda-Ledum associes*),
6. Tamarack-spruce stage (*Larix-Picea associes*).

The rate of deposition of organic matter is considerably slower in the first three pond stages than in the latter three bog stages. Accumulation of organic matter reaches its greatest rate in the sphagnum-bog heath stage. The Wayzata wetland is nearing the end of the bog-meadow stage.

Groundwater or saturated soil conditions and the resulting control they have on the microbial activity and the decomposition of the organic matter is in part the cause for the existence of the wetland.

With increased activities of man, the wetland condition has been altered by a restriction that has been formed by the construction of LaSalle Avenue along the southern boundary with an outlet consisting of 25 cm (10 in) clay tile. The result of these alterations is to generally lower the normal seasonal water level, resulting in greater stormwater storage capacity. To some degree, this increases the retention time of the stormwater in the wetland, however, resulting water level fluctuation is in excess of those that occurred naturally. The fluctuation is illustrated in Figure 18, Groundwater Fluctuation - Observation Well 1.

Groundwater observation well 1 is located near the entrance of the pilot zone and has a ground elevation of 29.2 m (95.80 ft). This is approximately 0.70 m (2.3 ft) above the invert elevation of the outlet flume.

As illustrated in Figure 18, the groundwater levels in the wetland are very responsive to precipitation and runoff events. The maximum fluctuation recorded during the study period was 0.46 m (1.5 ft) from a low elevation on December 30, 1974 to a high elevation on June 17, 1975. The water level elevations recorded at observation well 1 were generally 0.31 m (1 ft) above those recorded at the outlet, indicating a hydraulic gradient of approximately 0.0014.

The wetland or organic soils are the result of the deposition of plant and other organic material at a rate greater than the decomposition rate. These plant materials when first deposited contain substances readily used and hence rapidly decomposed by microorganisms to meet demands for the carbon and energy needed in their growth. With the readily available components used up in a few days to a few weeks, the bulk of the residues are degraded or partially degraded at a slower rate. Cellulose components, for example, are broken down relatively

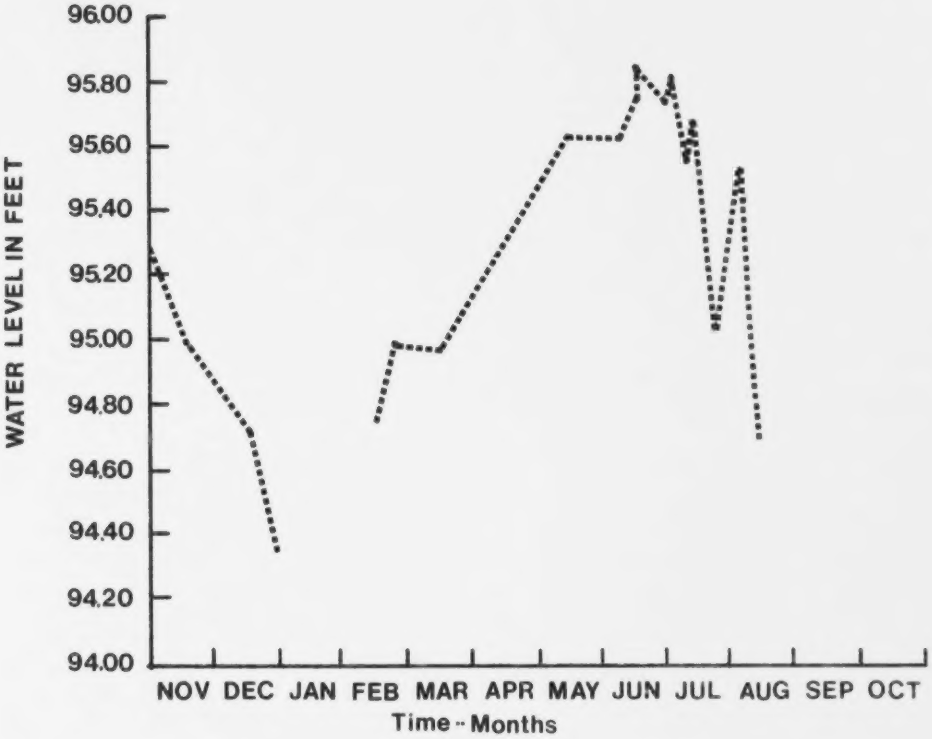


Figure 18. Groundwater Fluctuation - Observation Well 1

completely and rapidly, whereas lignin and lignified material is modified slowly over periods of months and years. The more resistant organic matter which thus slowly accumulates serves as not only the nutrient base for microorganisms, but a physical base as well. Root penetration into the accumulating organic matter provides microorganisms with more available organic materials than leak out of the roots or are contributed when roots die. Roots also serve to introduce oxygen into the organic environment close to the root surfaces.

The high moisture content and the compact structure of the organic soil allow surface layers to become slowly aerated as the water table drops. Under these conditions fresh organic matter is utilized by aerobic microorganisms with concomitant consumption of oxygen, leading to the depletion of oxygen in the saturated organic soil. With oxygen consumed and respiratory carbon dioxide released, the saturated organic soil becomes anaerobic, and the microbiological activity is continued only by those forms that can grow in the absence of oxygen.

Anaerobic metabolism results in only partial decomposition of the organic environment, and it follows that the fresh residues of one year become deposited on the still only partially degraded remnants of previous years.

The microbial population of the wetland is in equilibrium with the organic soil environment. The equilibrium is manifested in terms of population density, the magnitude of which is determined largely by the nutritional availability of the organic matter. A change in the environment in the form of fresh plant residue additions (autumn leaf fall, frost-die-back) will be reflected in a sharp increase with population density. A less pronounced change occurs with slow aeration and will be more evident as a change in the nature of the microbial population than as a marked population increase.

The quality of the groundwater in the wetland was extremely variable for all parameters analyzed. Table 12 presents the concentration of ammonia nitrogen and total phosphorus measured in observation wells 1, 5 and 9. The ammonia nitrogen concentration in observation well 1 varied from a low of 1.61 mg/l to 15 mg/l. Observation well 5, located in the pilot section, has the smallest range of concentration, from 7.19 mg/l to 24.29 mg/l, but had the highest average concentration of ammonia nitrogen, 15.19 mg/l. Observation well 9 showed the greatest range in concentration of ammonia nitrogen from 5.7 mg/l to 28.5 mg/l. Observation well 9 is located in the control section. Observation wells 1 and 9 averaged 5.78 mg/l ammonia nitrogen concentration and 11.95 mg/l, respectively.

Observation well 1 recorded the lowest total phosphorus concentration range from 0.01 mg/l to 0.76 mg/l with an average concentration of 0.23 mg/l. Observation well 5 had the highest average total phosphorus concentration, 0.85 mg/l with a range of 0.07 to 2.63 mg/l. The total phosphorus concentration in observation well 9 ranged from 0.09 mg/l to 1.66 mg/l with an average concentration of 0.62 mg/l.

A statistical analysis did not reveal any correlation between the total phosphorus and ammonia nitrogen values recorded in the groundwater.

Table 13 indicates little change in heavy metal concentrations during the study period in the groundwater of the wetland. The lead concentration ranged from <0.1 μg/l to 0.8 μg/l and zinc concentrations ranged from 0.01 μg/l to 5.0 μg/l.

The importance of the microorganisms as agents of mineralization and degradation, in natural environments is amply recognized (23). When it becomes of interest to define these functions in relation to a particular environmental situation, certain inherent difficulties must be recognized. Microorganisms

TABLE 12. COMPARISON OF NUTRIENT CONCENTRATIONS IN THE GROUNDWATER

	Observation Well 1		Observation Well 5		Observation Well 9	
Date	TP mg/l	NH$_3$ mg/l	TP mg/l	NH$_3$ mg/l	TP mg/l	NH$_3$ mg/l
11-5-74	0.18	10.13	0.26	7.19	0.28	8.17
12-13-74	0.01	1.61	0.81	20.31	0.66	6.67
12-30-74	0.01	2.76	2.63	13.68	1.66	8.90
1-29-75	0.01	2.19	0.30	15.31	0.68	12.19
2-17-75	0.76	4.30	2.05	17.09	0.33	11.96
3-3-75	0.37	4.76	--	--	--	--
3-11-75	0.06	1.94	--	--	--	--
4-1-75	0.26	5.50	--	--	--	--
5-15-75	0.22	4.50	0.87	11.0	0.50	10.00
5-27-75	0.62	14.02	0.29	21.03	0.09	28.50
6-6-75	0.02	7.77	0.53	24.29	0.15	11.77
6-16-75	0.67	3.10	1.34	7.62	1.50	5.71
7-2-75	0.13	15.00	0.97	23.31	0.42	16.31
7-11-75	0.10	4.95	0.32	13.00	0.19	14.38
7-18-75	0.16	9.19	0.28	15.91	0.72	16.38
8-7-75	0.07	5.17	0.07	10.25	0.11	6.50
11-4-75	0.19	3.03	1.17	8.28	1.34	7.83
Average	0.23	5.88	0.85	14.88	0.62	11.81

NOTE: TP = Total phosphorus
NH$_3$ = Ammonia nitrogen

TABLE 13. COMPARISON OF HEAVY METAL CONCENTRATIONS IN THE GROUNDWATER

	Observation Well 1		Observation Well 5		Observation Well 9	
Date	Lead μg/l	Zinc μg/l	Lead μg/l	Zinc μg/l	Lead μg/l	Zinc μg/l
1-29-75	0.20	0.60	--	--	<0.20	0.70
2-17-75	<0.20	1.70	<0.20	0.40	0.20	0.80
3-3-75	0.40	5.00	--	--	--	--
4-17-75	<0.10	0.02	0.10	0.75	0.80	0.24
5-15-75	<0.20	1.70	0.10	0.04	<0.10	0.03
5-27-75	0.10	0.05	--	--	--	--
7-11-75	<0.10	0.06	<0.10	0.01	--	--
Average	0.19	1.30	0.12	0.30	0.32	0.44

are nondescript morphologically, but extremely diverse, flexible, and responsive in their metabolic activities. These properties combined with the extremely small size of the microorganisms and the extreme complexities of natural environments sharply limit the analytical approaches which are both feasible and practical.

A significant indicator of microbial activity in natural environments is the amount of carbon dioxide evolved per unit time and the number of bacteria in the microbial environment. These parameters are especially useful because they reflect an overall summation of metabolic rates of a diverse population, and provides an indication of the amount and degradability of the major organic materials. Because the usual routine measurement of carbon dioxide evolution is subject to many shortcomings, close attention was paid to the design of the carbon dioxide experiment and to analysis of the resulting data.

The carbon dioxide evolved from the soils ranged from 7 to 310 mg per day for the 24-hour trials to 260 mg per day for the 72-hour trials. The daily average levels were lower for the 72-hour trial than the 24-hour trial. This indicates that atmospheric carbon dioxide made significant contributions to measurements. The 72-hour chambers were exposed one time, in the initial preparation for a sampling, to the atmosphere at which time air filled the chamber before it was sealed. Values obtained over the 72-hour period were averaged and divided by three to obtain the 24-hour value. The atmospheric contribution would thus be one-third the amount as for the 24-hour samplings. The longer trial period should, therefore, be a more accurate measure of the actual carbon dioxide production by the micro-flora. The 24-hour samplings are important in monitoring short-term fluctuations in activity and are important in that the daily fluctuations are illustrated. Unfortunately the actual fluctuation is somewhat dampened by the atmospheric contribution.

Microbial activity as reflected by carbon dioxide was monitored at 12 stations which are all located in and around the management area. Microbial activity as reflected by carbon dioxide evolved did differ substantially in carbon dioxide production between stations 7 and 12, however, the response to environmental conditions were very similar. Data based on 24-hour periods, for samples measured daily at these stations are shown in Figure 19, Carbon Dioxide Production - Control Area, Stations 7-12. The carbon dioxide evolved at station 7 was significantly greater than that at station 12, however, this probably is the result of the higher water table. Data from these stations were compared because both were outside the management area and are intended to reflect natural conditions.

Also plotted on Figure 19 are the 41 rainfall/runoff events that occurred during the sampling period. As is illustrated, there generally was a sharp decrease in the rate of carbon dioxide evolution following major rainfall/runoff events. Figure 20, Carbon Dioxide Production - 24 hours vs. 72 hours, Station 7, shows the degree of variation between the 24-hour and 72-hour

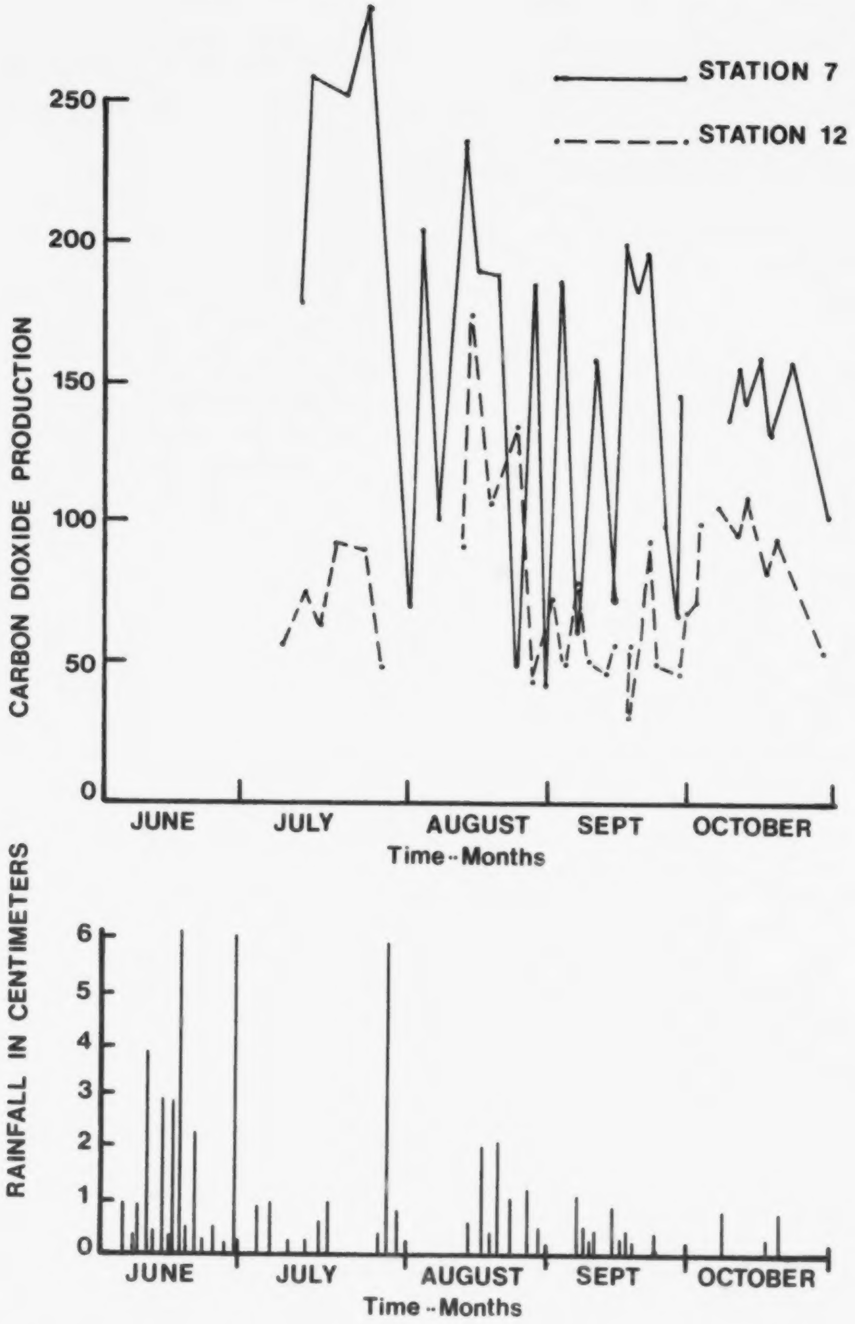


Figure 19. Carbon Dioxide Production - Control Area, Stations 7 - 12

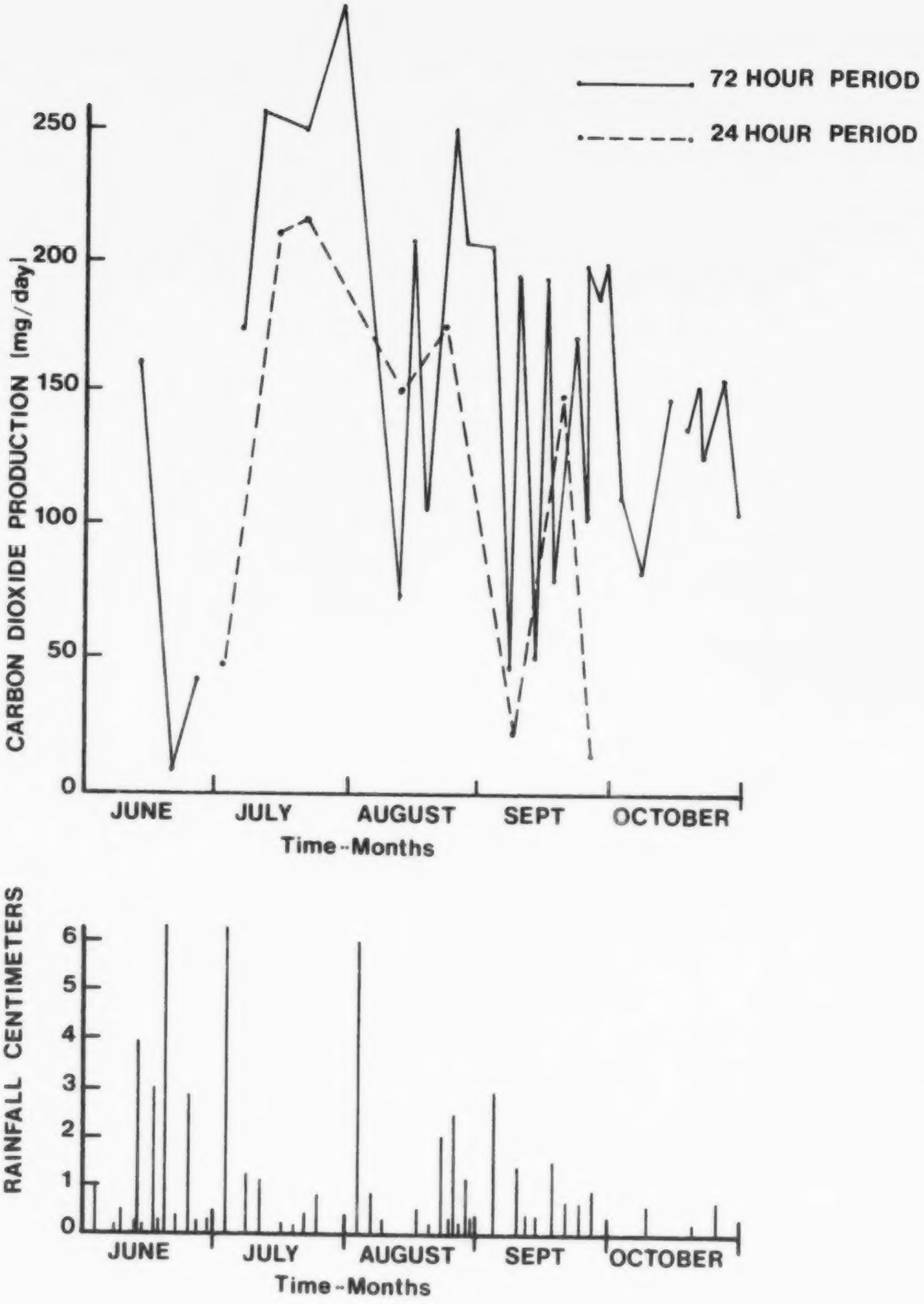


Figure 20. Carbon Dioxide Production - 24 Hours vs. 72 hours, Station 7

carbon dioxide evolution at station 7. These values are not adjusted for the atmospheric contribution to carbon dioxide and consequently the 24-hour carbon dioxide values are uniformly higher than those for the 72-hour run. However, the response to environmental conditions is very similar.

Estimation of microbial number is feasible and is a useful indicator to compliment carbon dioxide evolution studies.

Direct counts of bacteria for surface soils overall ranged from 9 x 10^8 to 164 x 10^8 bacteria per gram of dry soil. Largest populations were observed during the month of July for most stations. Conditions favorable for growth were optimum in the latter half of July; water was absent from the soil surface and ground temperature peaked. Fluctuating populations of slightly decreased size were observed during the fall samplings.

Direct microscopic enumeration of total bacteria per gram of marsh soil was carried out throughout the sampling period.

Counts taken at stations 7 and 13 served as controls to monitor sample variability and the basic reproducibility of the methodology used for direct microscopic counts.

Station 7 was located near the management area and consequently subjected to some degree of alteration, whereas station 13 was located in a relatively undisturbed area of the wetland. These two sites are located in areas that are similar in vegetation and micro-relief. The data are presented in Figure 21, Microbial Counts vs. Rainfall/Runoff Events, Stations 7 and 13. Population densities ranged from approximately 30 x 10^8 to 100 x 10^8 bacteria per gram of dry soil. The bacteria population were cyclic with some degree of regularity. Figure 17, page 54, illustrates that the lowest values were recorded during early June and late July, whereas the highest values were also recorded June and July.

The microbial activity is expected to be related to soil temperature, however, during late July a sharp decline in organisms was recorded, not only at stations 7 and 13 but at virtually all stations monitored. The soil temperature peaked during July and August and values up to 25°C (77°F) were recorded which are just within the optimal range of mesophilic growth. Soil temperatures were very stable and no abrupt changes were recorded, consequently, it is apparent that some factor other than soil temperature was responsible for the decrease in soil bacteria.

Comparing the soil bacteria counts for both stations 7 and 13 with rainfall/runoff events, it is apparent that surface bacterial counts respond to rainfall/runoff as indicated in Figure 21.

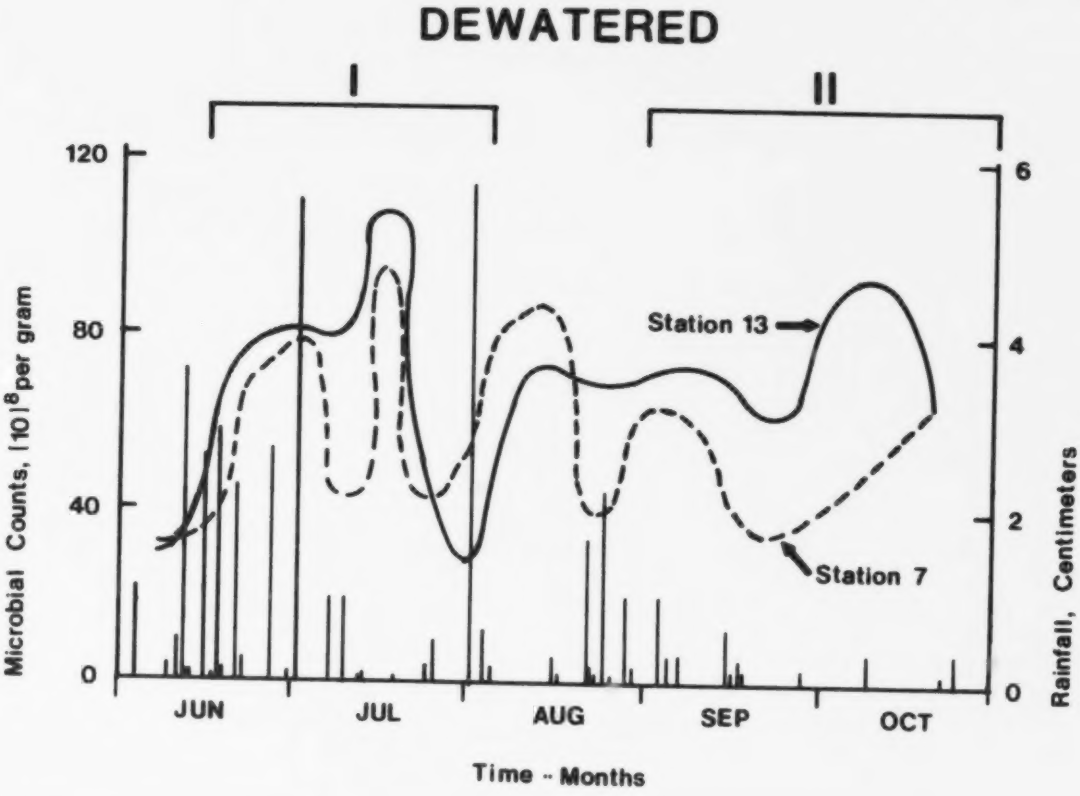


Figure 21. Microbial Counts vs. Rainfall/Runoff Events - Stations 7 and 13

Episodes of high rainfall caused sharp decreases in the rates of carbon dioxide evolution, as levels dropped to half the pre-precipitation value or even more than that. Return to previous carbon dioxide release rates occurred three to four days after a rainstorm in both the control and dewatered areas. The effect of the heavy rainfall on carbon dioxide evolution was probably due to the increased moisture content of the surface zones. With the pre-rainfall equilibrium of dissolved/gaseous carbon dioxide altered by soil saturation, a greater proportion of the carbon dioxide was dissolved until a new equilibrium was attained. Microbial activity may also have slowed somewhat with sudden saturation of the habitat, but this probably was less important than the carbon dioxide solution effects.

The basic agreement between the two stations is obvious, attesting to the validity of the counting procedures and to the reliability of the fluctuations observed.

Wetland Management

One of the main objectives of the wetland study was to evaluate possible methods or techniques in which the nutrient removal capacity of a wetland could be enhanced. With this objective in mind, a management area was set up consisting of two individual test plots.

It was theorized that by regulating the water level in the wetland the microbial activity could be increased and consequently the nutrient removal capacity of the wetland enhanced. The specific objectives were to determine that if by regulating the water level, could the microbial activity be stimulated, and if so, what would be the resulting impact on water quality changes?

The data collection stations associated with the pilot zone and those associated with the control zone were located as shown in Figure 12, page 29.

The pilot zone was dewatered twice during the summer of 1975. The first dewatering occurred during the period June 16 through August 1 and the second period was August 26 through November 11.

Pumping at a rate of 120 gpm, approximately 36 hours of pumping was required before maximum dewatering of the pilot zone was attained.

A continuous pumping rate of 15 gpm was required to keep the area dewatered.

Comparisons were made on paired sets of stations with one member of the pair in the control zone and the other member located in the pilot zone. The pilot zone was subject to manipulation of the water table, while counterpart stations in the control zones were subjected to the normal water table of the marsh.

When the data was analyzed for all stations, it became evident that water table changes did cause substantial changes in the microbial system where water level management was effective.

The water table of the pilot zone was lower than the control zone by several inches for most stations and three feet for station 4. Thus, station 4 was the driest location within the wetland. The highest water table was consistently found at station 10, often this area was covered by standing water. Comparison of these two stations would be expected to show the greatest microbial differences because soil conditions of the dry station 4 would greatly differ from the wetter station 10.

Stations 4 and 10 demonstrate the distinct differences in water table expected of pilot versus control zone stations. Pumping capacity at station 4 was obviously adequate to lower the water table significantly and hence allow for substantially better aeration than occurred in the more nearly saturated soil of station 10.

A summary of the data derived from measurements of the depth of water table below the soil surface for paired stations 4 and 10 is shown on Figure 22, Depth to Groundwater - Stations 4 and 10.

Located in the pilot zone and subjected to pumping, site 2 can be seen to be virtually identical to the unpumped counterpart site 8 in terms of water level.

The corresponding data for paired stations 2 and 8 is presented similarly on Figure 23, Depth to Groundwater - Stations 2 and 8.

The course of carbon dioxide evolution at stations 4 and 10, based on 24-hour periods of carbon dioxide absorption, is summarized on Figure 24, Carbon Dioxide Production - Stations 4 and 10, 24-hour. Although some variations are evident, the trend is clearly in the direction of higher respiratory activity at the well drained station 4 than at the counterpart station 10 where the water table remained within 25.4 cm (10 in) of the surface. It is of interest to point out the difference in response of carbon dioxide production at stations 4 and 10 following the rainfall events of July 1 and August 1, 1975 during which 5.59 cm (2.20 in) and 5.72 cm (2.25 in) of precipitation were recorded, respectively. Carbon dioxide production at station 4 shows a gradual response as a result of the rainfall events whereas station 10 responded with almost an immediate drop in carbon dioxide production following the July rainstorm event. It appears that the carbon dioxide production at station 10 was much more responsive to rainfall events, however, there was little correlation. This can partially be explained by the fact that runoff did not occur with each rainfall event, consequently the magnitude and intensity of the rainfall event had some bearing. Results for the 72-hour absorption experiments are similar but disclose greater differences in carbon dioxide evolution between stations 4 and 10 as shown on Figure 25, Carbon Dioxide Production - Stations 4 and 10, 72 hour. Respiratory activity remained at high and relatively stable rates from late July through mid-September.

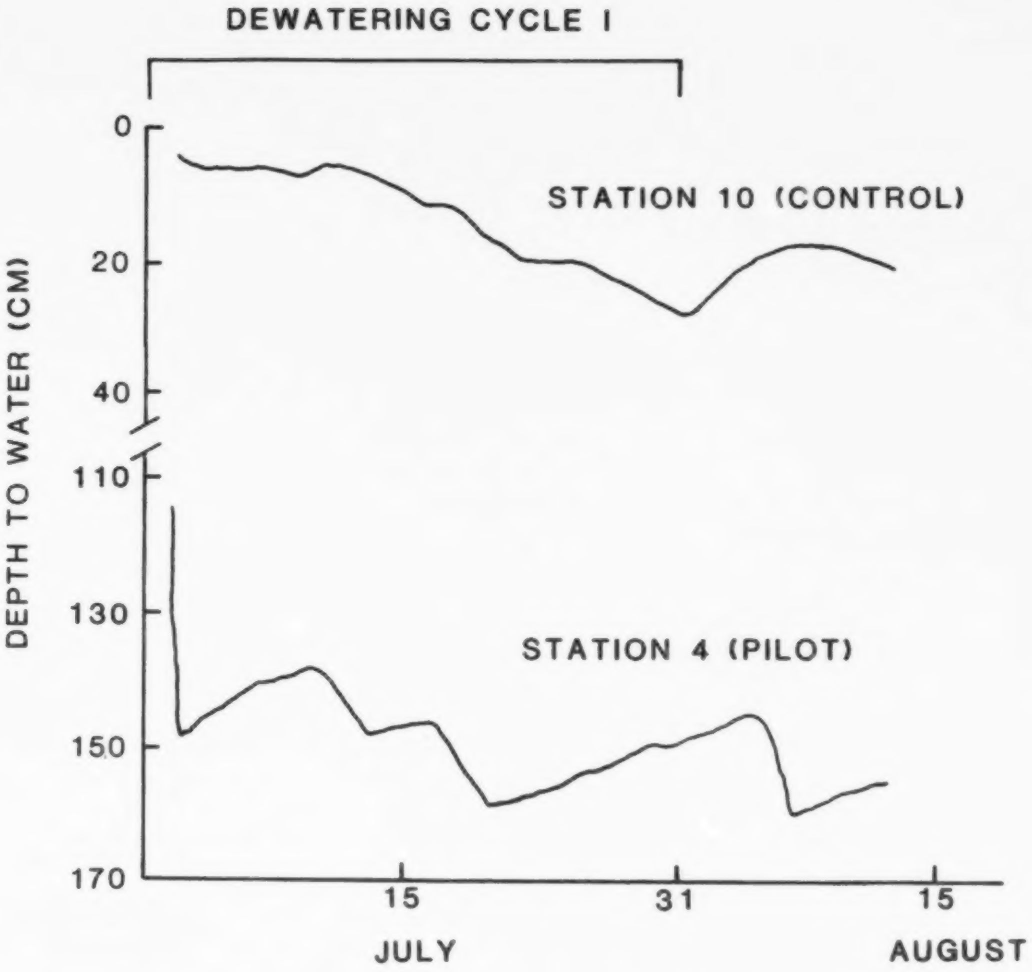


Figure 22. Depth to Groundwater - Stations 4 and 10

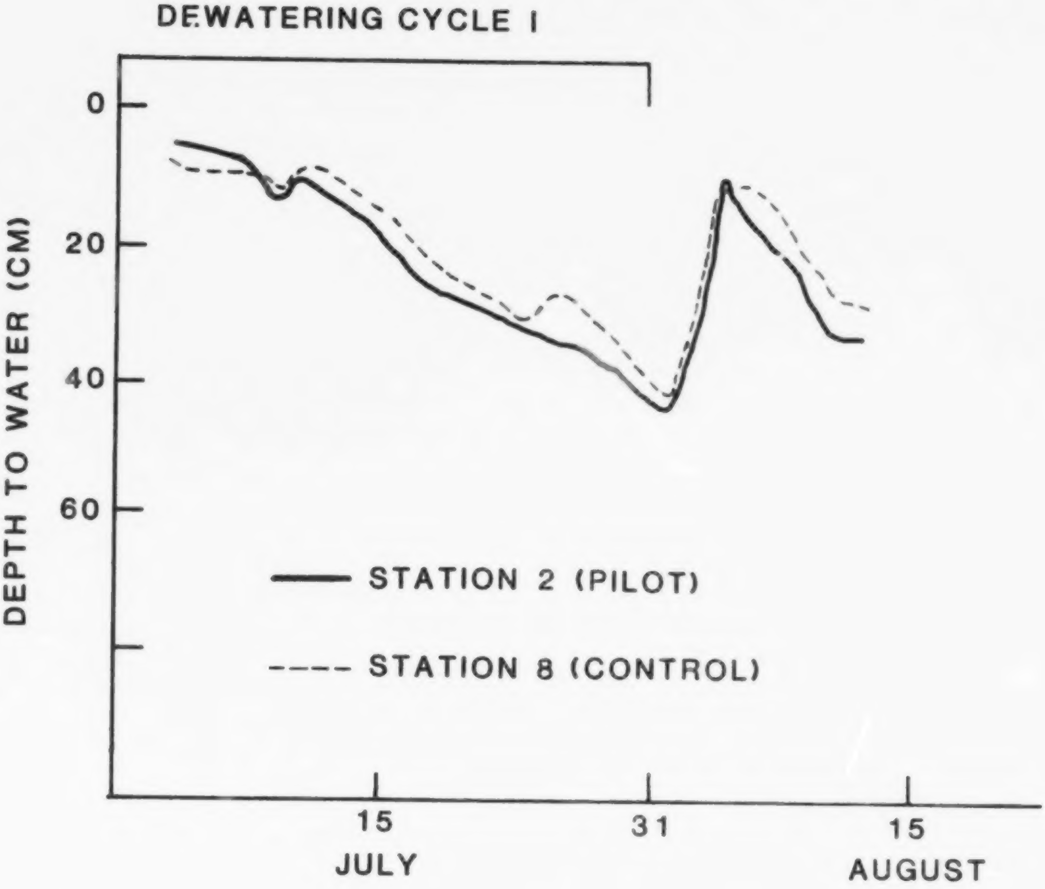
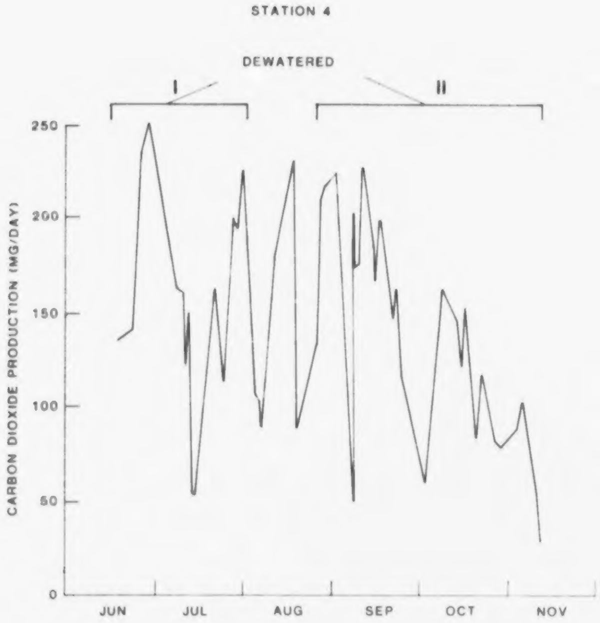


Figure 23. Depth to Groundwater - Stations 2 and 8



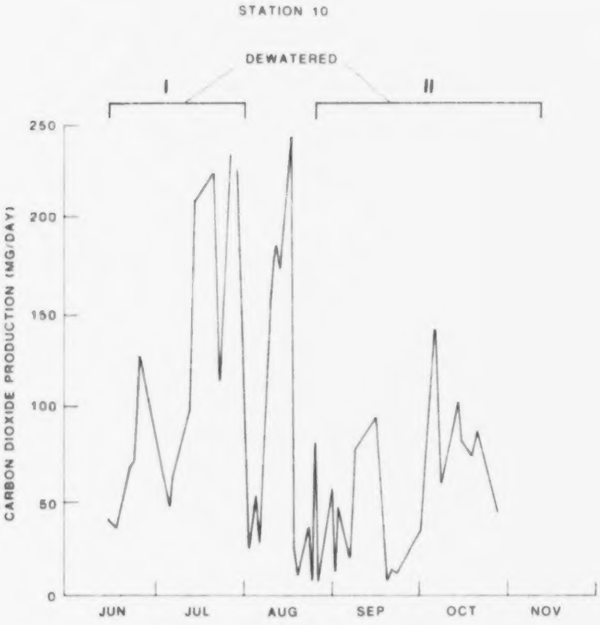


Figure 24. Carbon Dioxide Production -
Stations 4 and 10, 24 Hour

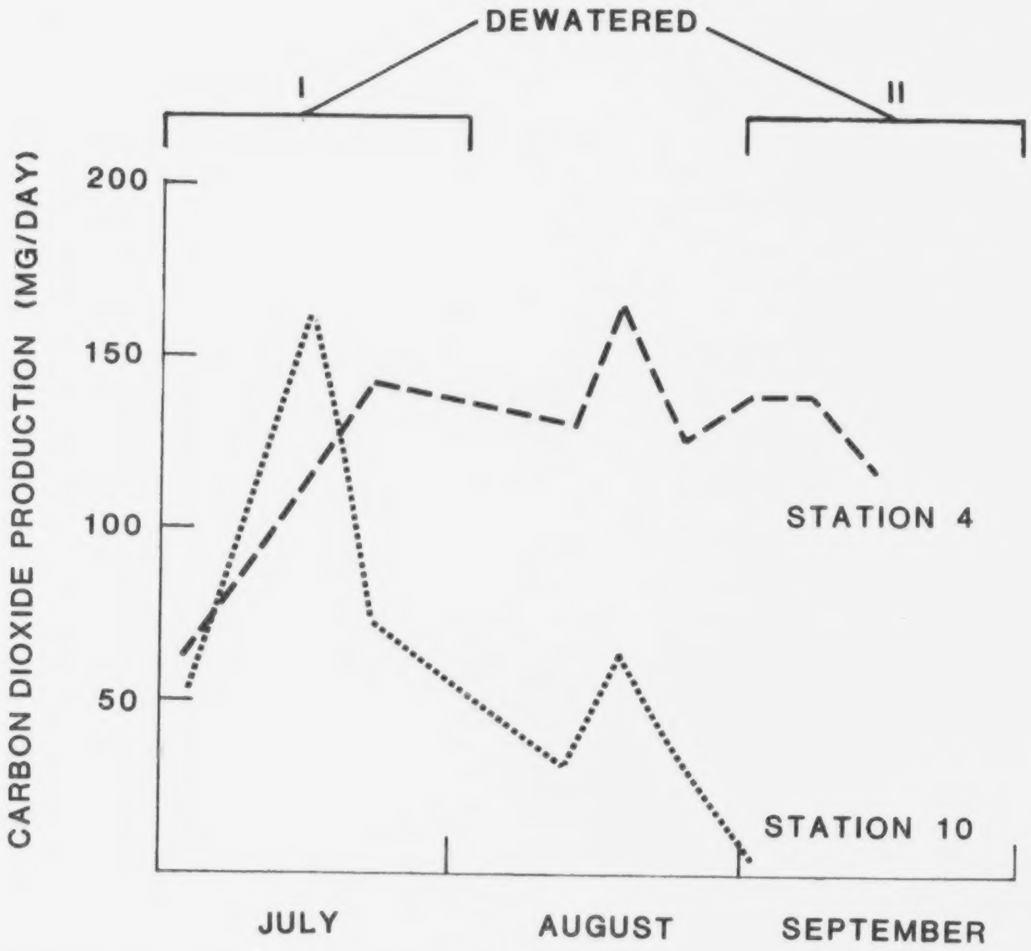


Figure 25. Carbon Dioxide Production - Stations 4 and 10, 72 Hour

Enumeration data for paired stations 4 and 10 are given in Figure 26, Surface Microbial Counts, Stations 4 and 10. These data are for surface samples. Populations ranged from about 15 x 10^8/gram in early spring to approximately 10 times that as the maximal population occurring in mid-summer. Bacterial numbers increased from early June through early August, with generally lower numbers through September and October. There were clearly greater numbers of bacteria per gram at surface station 4 (well drained) than at surface station 10 (high water table). Additional counts were made at stations 4 and 10 from subsurface samples taken at a depth of 76 cm (30 in). These data are summarized in Figure 27, Subsurface Microbial Counts Stations 4

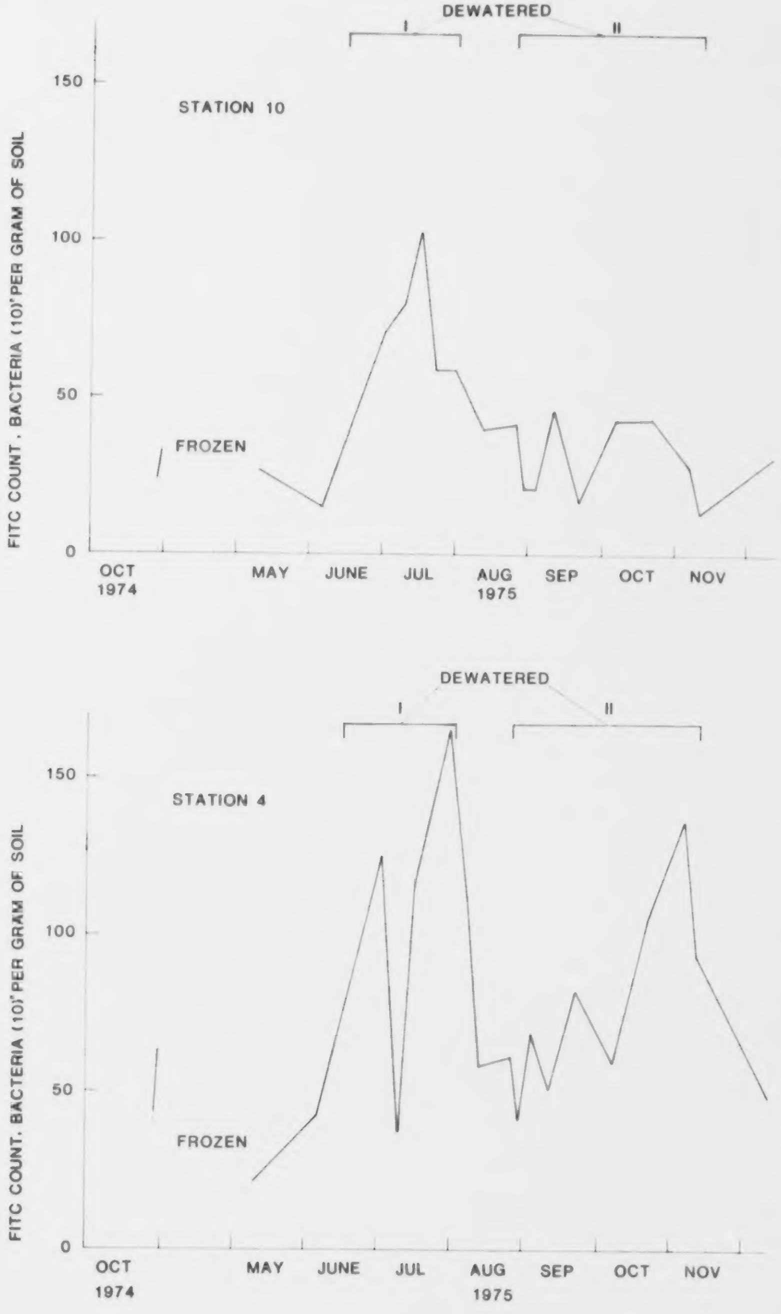


Figure 26. Surface Microbial Counts -
Stations 4 and 10

and 10. In contrast to the surface samples, the two subsurface stations were very similar with respect to population density and seasonal patterns. These findings are consistent with the concept that surface populations are more diverse and numerous than subsurface populations. The high population recorded for the subsurface stations 4 and 10 during early June is difficult to interpret. Hydrologically the wetland was very active and significant flows in the order of 200 gpm were occurring at the outlet. Consequently, the soil water system was actively moving and the high early counts may be in response to the availability of nutrients.

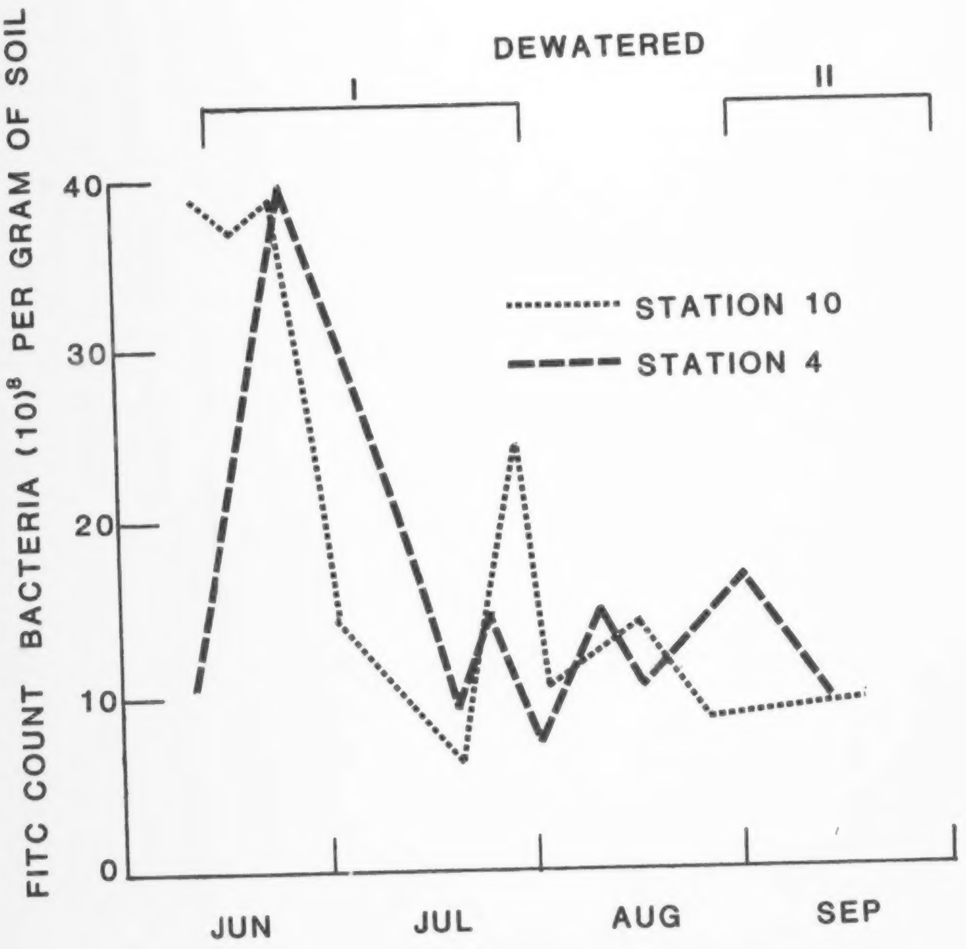


Figure 27. Subsurface Microbial Counts - Stations 4 and 10

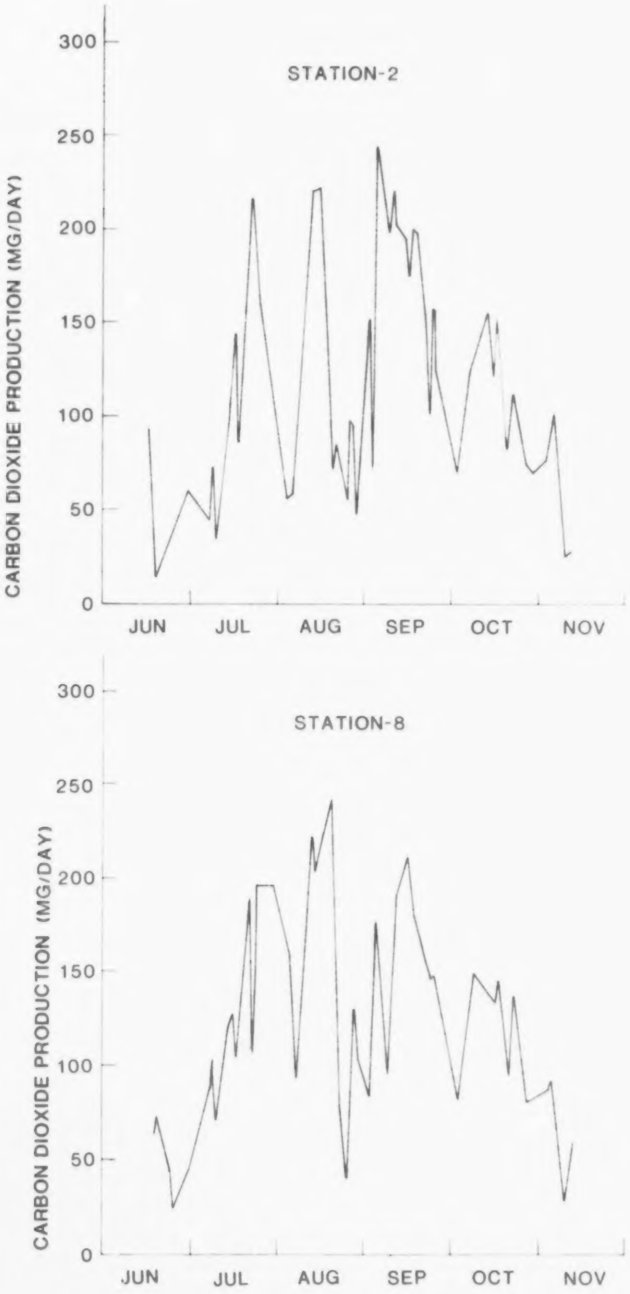


Figure 28. Carbon Dioxide Production - Stations 2 and 8, 24 Hour

Microbial activity as reflected by carbon dioxide evolved did not differ substantially between stations 2 and 8. Data, based on 24-hour periods, for samples measured daily at these stations are shown on Figure 28, Carbon Dioxide Production - Stations 2 and 8, 24 hour. Periods during which the pumps were operative in the pilot zone are also shown in the figure, appearing as horizontal lines near the top of the graph. Pumping was relatively ineffective and microbial activity (carbon dioxide evolved) was only slightly lower at unpumped, control station 8 than at pilot station 2. Stations 2 and 8 must be treated as duplicate samples since they were chosen originally for similarities in vegetation and location, and since the expected variable, water level, proved to be similar in each. Agreement between these duplicate samples were good. Carbon dioxide evolution over a 72 hour period in the vicinity of stations 2 and 8 is shown on Figure 29, Carbon Dioxide Production - Stations 2 and 8, 72 hour.

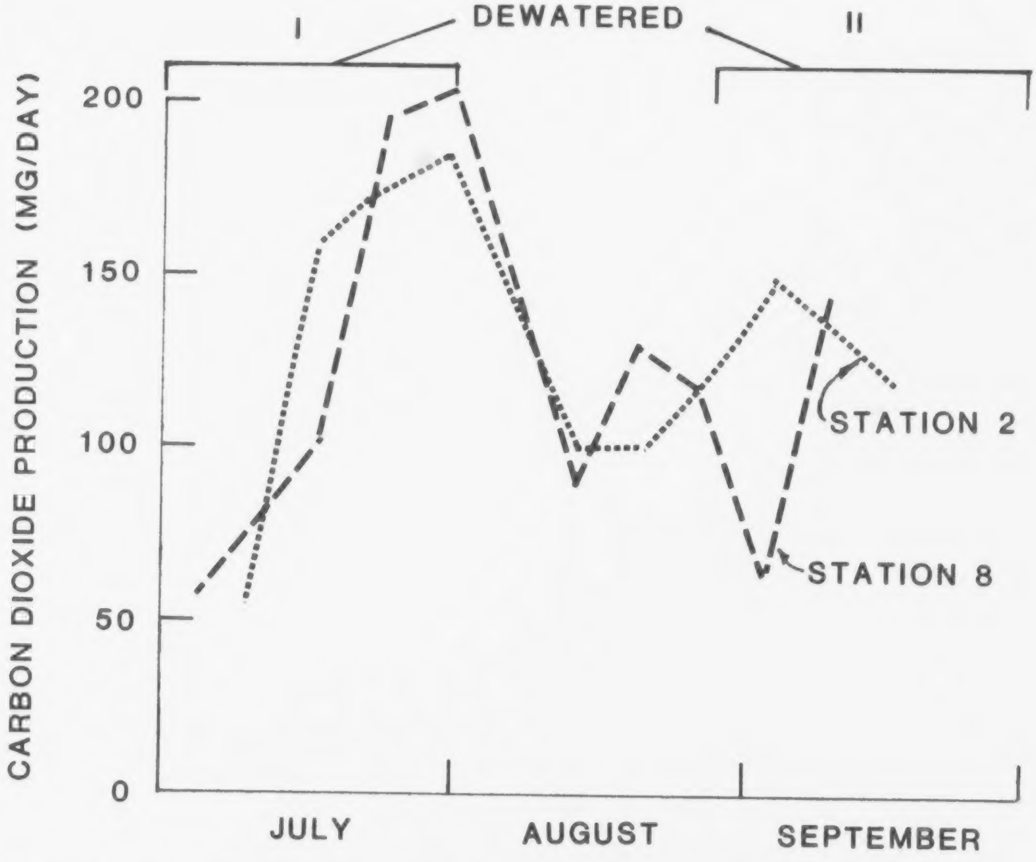


Figure 29. Carbon Dioxide Production - Stations 2 and 8, 72 hour

Results of counts on paired stations 2 and 8, which varied only slightly in depth of water table, showed general agreement in total numbers. The data are summarized in Figure 30, Surface Microbial Counts, Stations 2 and 8. Population densities ranged from about 20 x 10^8/gram to 100 x 10^8/gram. Numbers were lowest in early June, increasing throughout June, and high during July. After a decline in the second half of August, numbers were steady through much of September and October.

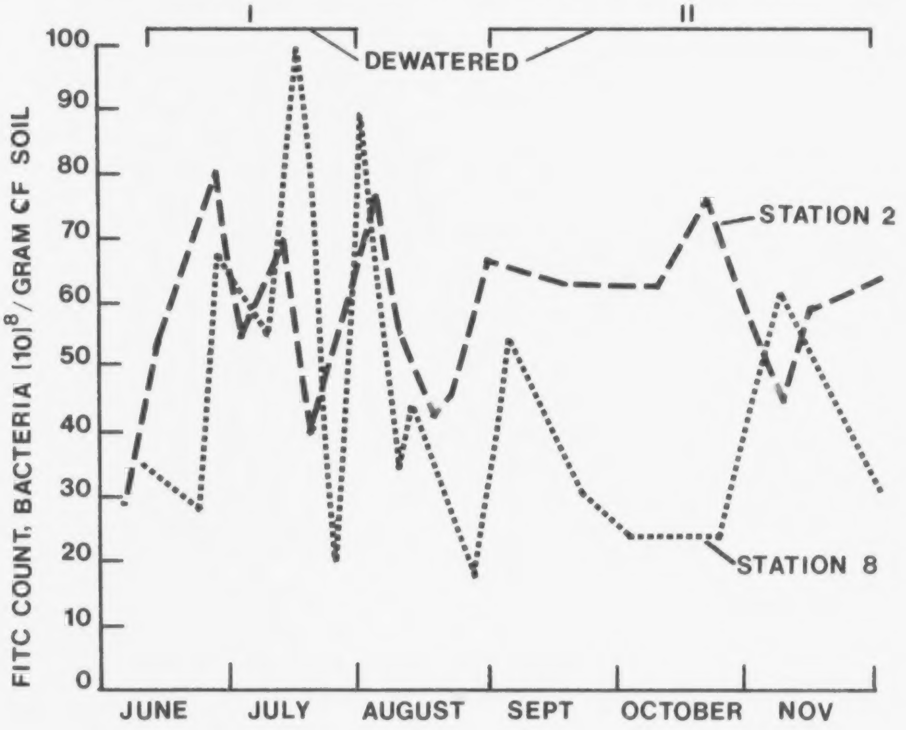


Figure 30. Surface Microbial Counts - Stations 2 and 8

One of the main objectives of the Wayzata wetland project was to determine the impacts the wetland has on the quality of stormwater passing through the wetland and also if any water quality improvement that occurs in the wetland can be enhanced.

As mentioned earlier, the pilot and control management area was set up and regulated in order to determine if water level management in the wetland would stimulate microbial activity and consequently enhance the water quality passing through the wetland ecosystem.

Figures 31, 32 and 33 were constructed utilizing the data phosphorus levels in the soil water, surface and subsurface microbial populations.

Figure 31, Surface and Subsurface Microbial Counts vs. Total Phosphorus Concentration in Soil Water - Station 6, is constructed from data obtained at monitoring station 6 and observation well 6. Monitoring station 6 is located outside the management area approximately 2 m (6.6 ft) from monitoring station 5.

The most vivid feature of Figure 31 is the apparent relationship between soil water phosphorus levels and subsurface microbial populations during the month of June and early July. Figure 31 also indicates that when the level of phosphorus drops below some given value, the phosphorus level ceases to have an effect on the population of subsurface microbes. However, Figure 32, Surface and Subsurface Microbial Counts vs. Total Phosphorus Concentration in Soil Water - Station 10, does not illustrate this relationship. This may be due to the high water table condition at site 10 resulting in less variation in the type of microbes present.

There appears to be an almost inverse relationship between surface microbes and subsurface microbes and surface microbes and phosphorus.

The same relationship between subsurface microbes and total phosphorus is well illustrated at monitoring stations 5 and 10. Also, there appears to be an inverse relationship between surface microbes and subsurface microbes and total phosphorus. However, this relationship is not as apparent as is illustrated on Figure 31 of monitoring station 6.

There does not appear to be any relationship between ammonia nitrogen and biochemical oxygen demand parameters monitored at the sites and the surface and subsurface microbe population.

The apparent inverse relationship between aerobic microbes and total phosphorus could be the result of microbial immobilization of phosphorus resulting in lower equilibrium - solution levels. These results appear to agree with results obtained by B.B. Singh (24).

The most visible and the ultimate impact of the management program was the vegetative response to dewatering. A one meter square area was selected in both the pilot and control zone. The selection process required that these areas be as vegetatively similar as possible. The dominate vegetation was reed canary grass (Phalaris arundenacea). The vegetation was clipped approximately every ten days and immediately weighed. The first clipping occurred on July 10, 1975 and the final clipping occurred on August 12, 1975.

The results of the clipping are presented in Table 14.

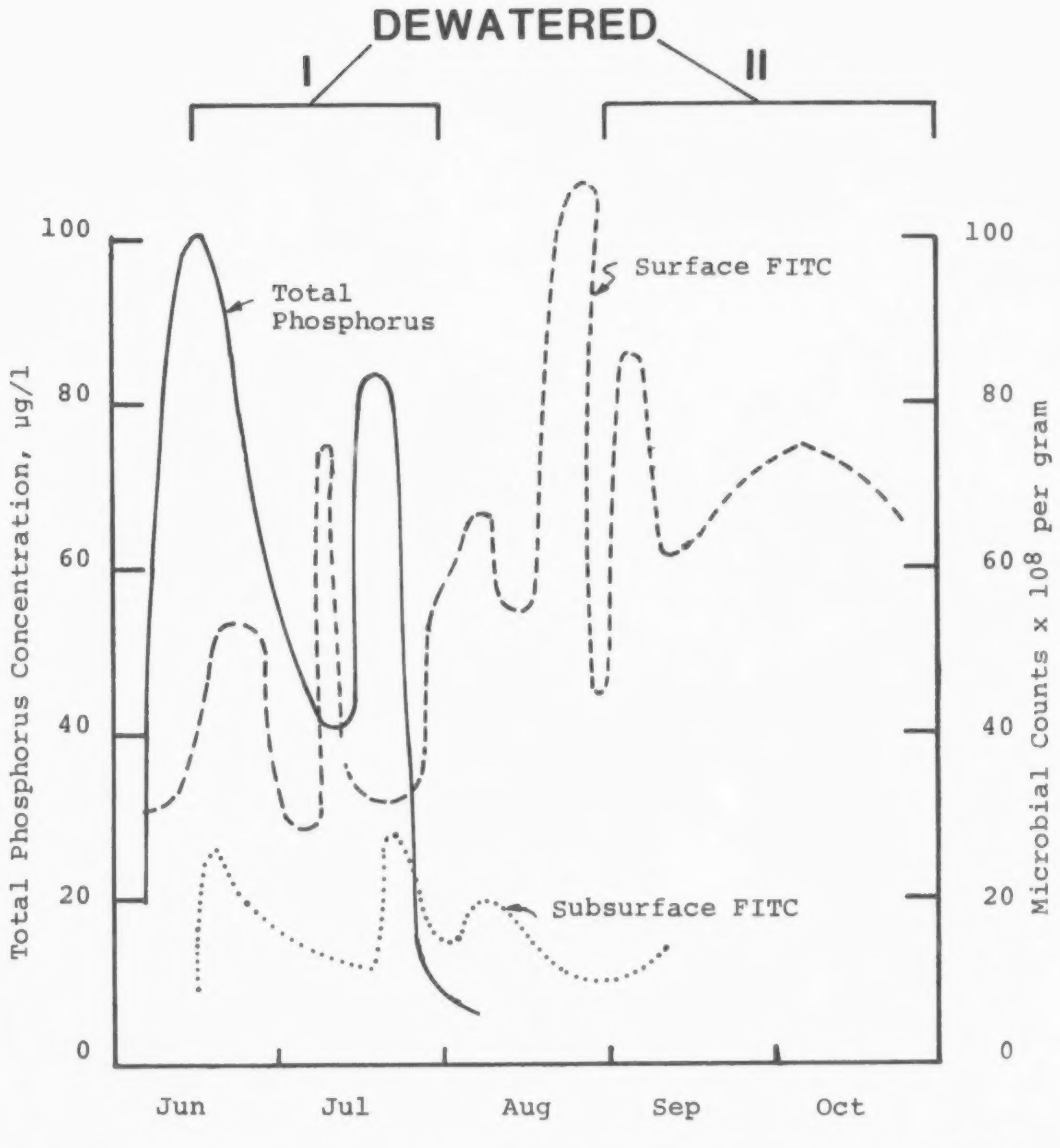


Figure 31. Surface and Subsurface Microbial Counts vs. Total Phosphorus Concentration in Soil Water - Station 6

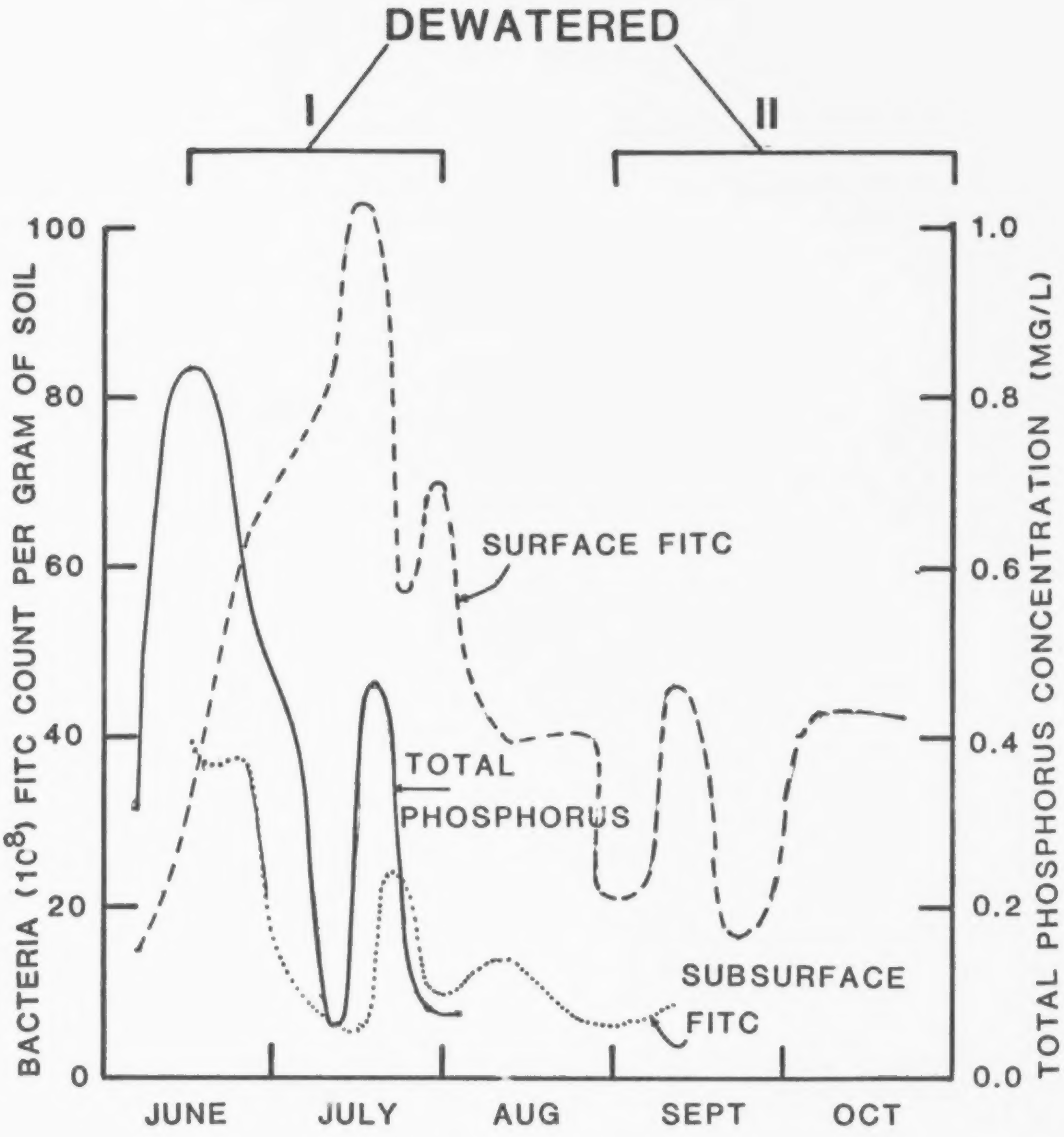


Figure 32. Surface and Subsurface Microbial Counts vs. Total Phosphorus Concentration in Soil Water - Station 10

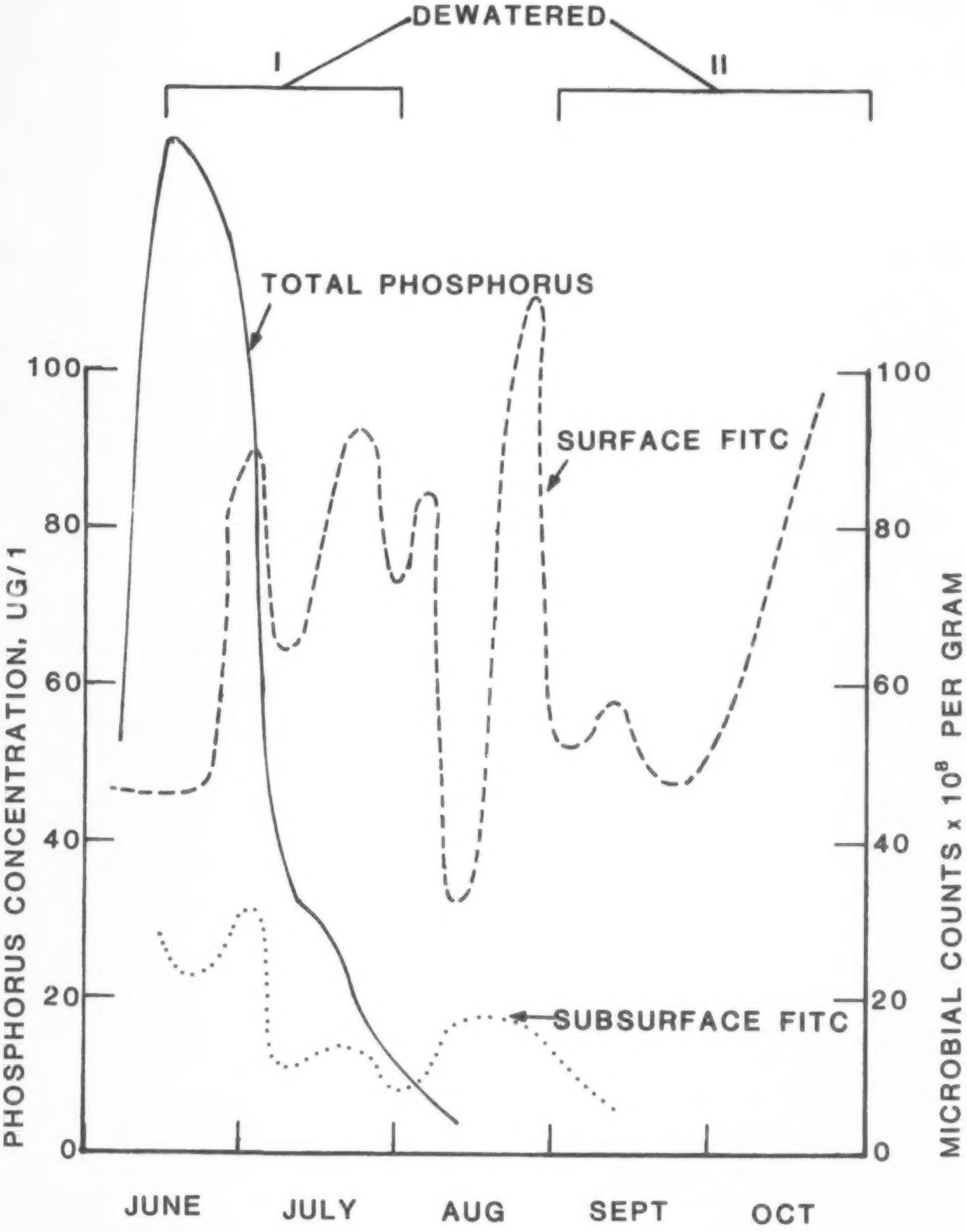


Figure 33. Surface and Subsurface Microbial Counts vs. Total Phosphorus Concentration in Soil Water - Station 5

TABLE 14. VEGETATIVE MASS PRODUCTION - WAYZATA WETLAND

Date	Vegetative Mass, kg/m^2 Pilot Zone	 Control Zone
July 10, 1975	2.04	0.749
July 21, 1975	0.518	0.269
August 1, 1975	0.173	0.084
August 12, 1975	0.110	0.087
Total	2.84	1.19

The results of this relatively brief monitoring of vegetative mass indicates that the vegetative growth in the dewatered zone produced approximately 2.84 kg/m^2 during the test period, whereas the control zone produced 1.19 kg/m^2. On a one term basis it appears that the dewatered pilot zone produced approximately 2.4 times the vegetative mass produced in the control zone.

Phosphorus sorption and desorption characteristics of soil is affected by organic residues (24).

Phosphorus has been shown to be the limiting nutrient in the lake eutrophication cycle and therefore, has a special significance to the Lake Minnetonka area. Consequently, an in-depth study was conducted on the marsh soils in order to establish the ultimate fate of phosphorus in the wetland. A total of 18 organic soil samples were collected in the vicinity of stations 4 and 10 for phosphorus analysis.

In order to check the validity of the results, three core samples were taken at stations 4 and 10. Three soil samples were selected from each individual core. The first sample was taken at approximately the 5 cm (2 in) depth, the second at approximately the 30 cm (17 in) depth and the third at approximately the 60 cm (24 in) depth.

The results of these analysis indicate that approximately 0.045 percent of the wetlands organic soil is phorphorus.

The average bulk density of the organic soil has been established at approximately 641 kg/cu-m (40 lbs/cu-ft). This value agrees well with the values reported in United States Department of Agriculture Circular 290 (R).

Assuming a bulk density of 641 kg/cu-m (40 lbs/cu-ft) and an average concentration of 0.045 percent phosphorus, approximately 0.288 kg/cu-m (0.018 lbs/cu-ft) of phosphorus is present in the organic soil.

In order to add more insight into the complex nature of the phosphorus cycle, phosphorus adsorption isotherms were constructed for the wetland soils. A method developed by A. W. Taylor and H. Kieuishi (25) for constructing phosphorus adsorption isotherms was utilized.

The results are calculated in terms of the ratio x/(1.0 + log c), where x is the weight of phosphorus adsorbed in the soil in mg/kg (ppm) and c is the final phosphorus concentration in mg/l. This ratio provides an index of the adsorption capacity of the soils. Together with data on the bulk density of the soil, the relative depth of the soil horizons and the anticipated composition of the influent water, this ratio may be used to calculate the adsorption capacity of the soil.

To determine the phosphorus adsorption, a five gram sample of each soil was added to a 100 ml volume of a solution containing 30 ppm phosphorus and 0.13 percent KCl and shaken for 18 hours on a reciprocating shaker. The suspension was then filtered and an aliquot of clear solution removed for analysis. The final phosphorus concentration was determined colorimetrically using the ammonium molybdate-ascorbic acid procedure.

Table 15 indicates that at a phosphorus concentration of 1 mg/l, the range in phosphorus adsorption isotherm at stations 4 and 10 illustrates the shape of the isotherm for the various soils.

TABLE 15. PHOSPHORUS ADSORPTION CHARACTERISTICS - WAYZATA WETLAND SOILS

Sample	Station	Depth (cm)	Phosphorus Adsorption (ppm) (1 mg/l)	Phosphorus Adsorption (ppm) (30 mg/l)
1	4	5	81.3	232
2	4	30	28.5	269
3	4	60	35.8	431
4	10	5		264
5	10	30	35.6	251
6	10	60	26.5	339

The average measured value for phosphorus in solution at stations 4 and 10 was approximately 0.9 mg/l. Consequently, one would assume that the amount of phosphorus present in the wetland soils would be in the order of 26 to 81 ppm or 165 to 518 kg/ha-m (45 to 141 lbs/ac-ft). However, the digestive results indicated that approximately 2,868 kg/ha-m (780 lbs/ac-ft) of phosphorus was present in the organic soil. Consequently, the organic soil in the Wayzata wetland presently contains from 5 to 17 times the amount of phosphorus that the isotherm indicates that it should hold as indicated in Figure 34, Phosphorus Adsorption Isotherms -

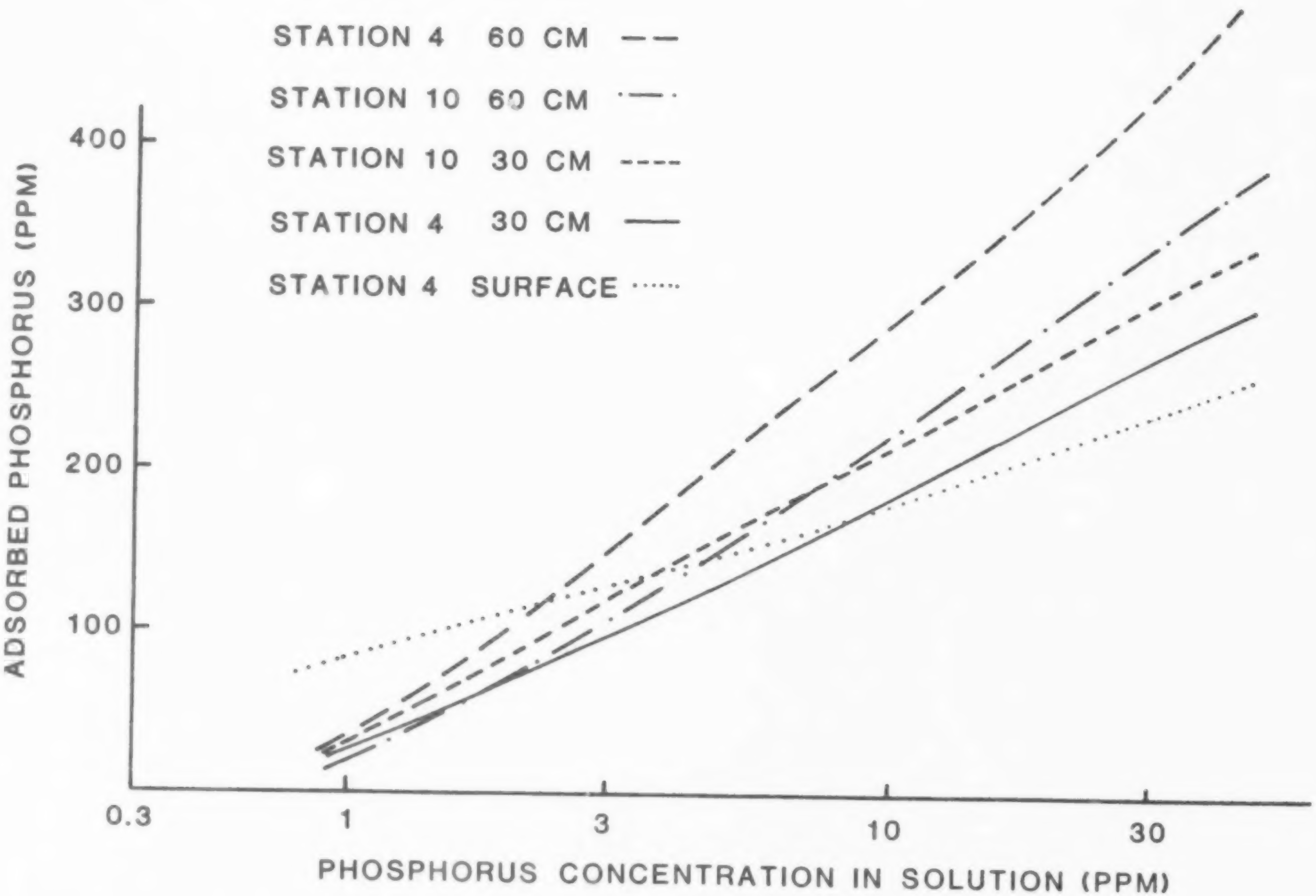


Figure 34. Phosphorus Adsorption Isotherms - Stations 4 and 10

Stations 4 and 10.

These values are high for an organic soil, however, they appear reasonable when considering the relatively larger percent of inorganic material present in the soil profile as shown in Figure 5, page 16.

It is apparent that the phosphorus is fixed in some organic form, possibly as part of the vegetative fiber.

If this additional phosphorus is organically based, stimulation of the biological system will remove greater quantities of phosphorus. The results of the vegetative plots indicate that significant quantities of organic matter were produced. Research (26) has shown that by the time a plant has obtained approximately 25 percent of its total dry weight it has acquired 75 percent of its total phosphorus needs. Experimental results by Spangler et al. (27) indicate that frequent harvesting of bulrushes removed greater quantities of phosphorus than a single harvest even though the total organic matter removal was not substantially greater.

Sump Water Quality

The frequent analysis of water quality for the sump pumping station provides a detailed picture of nutrient concentrations. The control of water elevations within the pilot area would be expected to alter the water quality at the sump, the result of changing environmental conditions and thus biological activity. A comparison of water quality for sump versus outlet would be comparable to pilot zone versus control zone. Pilot zone versus control zone comparisons yielded significantly different water quality for three parameters: ammonia nitrogen, phosphorus and total suspended solids. Biochemical oxygen demand, total coliform and oxidation reduction potential appear to be minimally affected by manipulation of water levels. The effect of dewatering upon the pilot zone was distinctly different for the two dewatering cycles, I and II, studied attesting to the pronounced effect uncontrollable parameters have upon the pilot zone.

Sump Water Quality - Total Coliform--

Total coliform counts of the sump follow an erratic pattern, ranging from 0-322 colonies per 100 mls. See Figure 35, Total Coliform, Total Suspended Solids and Biochemical Oxygen Demand Concentrations in Sump Discharge Water. The standard mean was 59. The appearance of the occasional high counts does not appear to be related to any monitored parameter. Such fluctuations in total coliform counts are common. The source of the coliform are natural soil inhabitants and animal fecal contamination. It is considered that within these observed ranges for total coliform contaminated water would not be a problem.

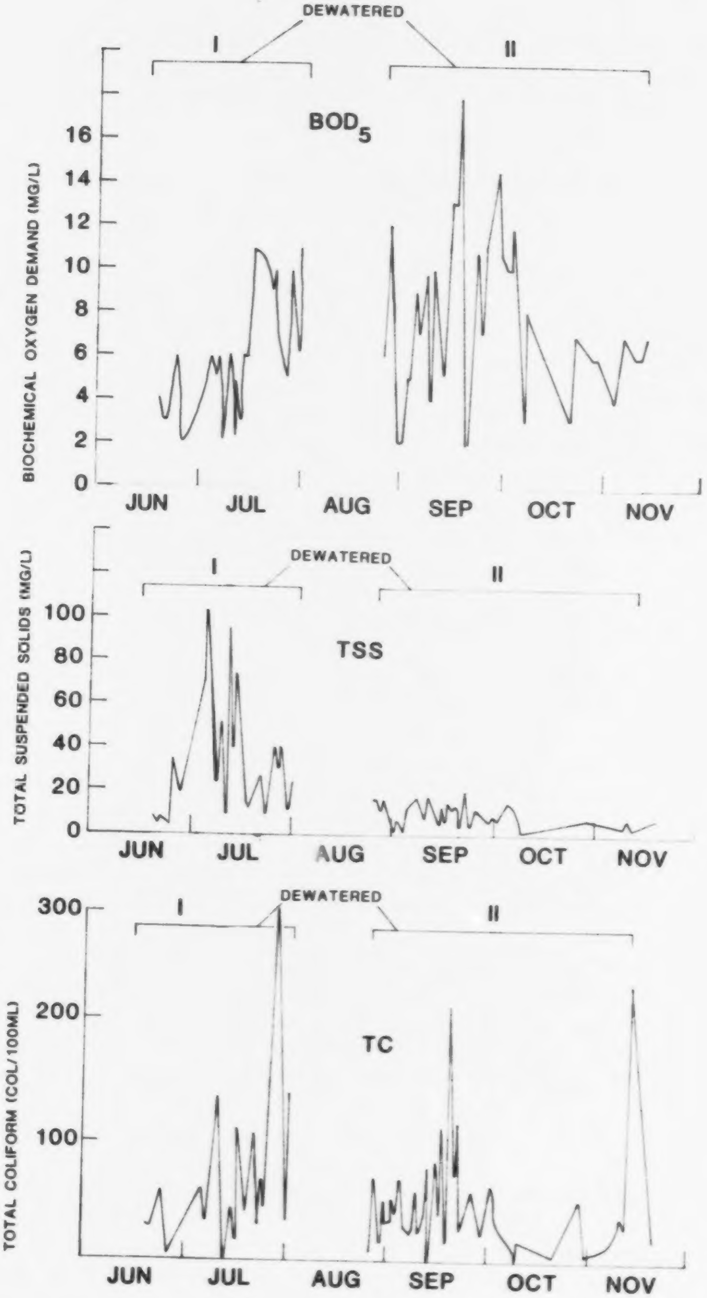


Figure 35. Total Coliform, Total Suspended Solids and Biochemical Oxygen Demand Concentrations in Sump Discharge Water

Total coliform of the sump and outlet were similar but no distinct patterns were observed. See Figures 35 and 36. The mean value was slightly lower for the sump. The outlet ranged 0-240 colonies per 100 mls, the mean was 71 over the same period.

Sump Water Quality - Biochemical Oxygen Demand--

Biochemical oxygen demand values of the sump ranged from 0-16 mg/l fluctuating greatly (see Figure 35). Values were slightly higher through September. Outlet values of biochemical oxygen demand ranged 0-14 over the same period. See Figure 36, Total Coliform, Total Suspended Solids and Biochemical Oxygen Demand in Outlet Discharge Water. The value of comparing biochemical oxygen demand over time and location is highly questionable, the nature of oxidizable material is unknown and variable. However, within the restriction of the wetland a comparison of biochemical oxygen demand may be fairly accurate. There does not appear to be a significant difference in biochemical oxygen demand for sump and control zones.

Sump Water Quality - Total Suspended Solids--

Total suspended solids of the sump showed a definite pattern (Figure 35). Highest values were found during dewatering cycle I, significantly lower values were seen during dewatering cycle II. Preceding and through the first two weeks of dewatering cycle I the wetland was infiltrated with stormwaters as a result of the excessive precipitation in June. The high volume of water stirs up the wetland soils as a result of increased flow rate and increases the suspended solids concentration.

Total suspended solids concentration values were greatly reduced through dewatering cycle II during which less precipitation fell. The wetland soils received smaller increments of inflow resulting in lower flow rates such that suspended solids settle out. The need for controlled flow rates is seen as a means of reducing total suspended solids.

Total suspended solids values of the outlet were subject to larger fluctuations than the sump. See Figure 36. Outlet values ranged 0-270 mg/l, sump values ranged 0-104 mg/l over the same period. The high peaks observed at the outlet were due to disturbance of sediments in the bed of the outlet channel. These high peaks were reduced or absent for the sump due to the difference in manner of discharge for the outlet and sump.

Sump Water Quality - Ammonia Nitrogen--

Ammonia values in sump discharge ranged from 0.1-15 ppm, with concentrations fluctuating greatly June through July but remaining almost constant from September through November. See Figure 37, Ammonia Concentration and Oxidation Reduction Poten-

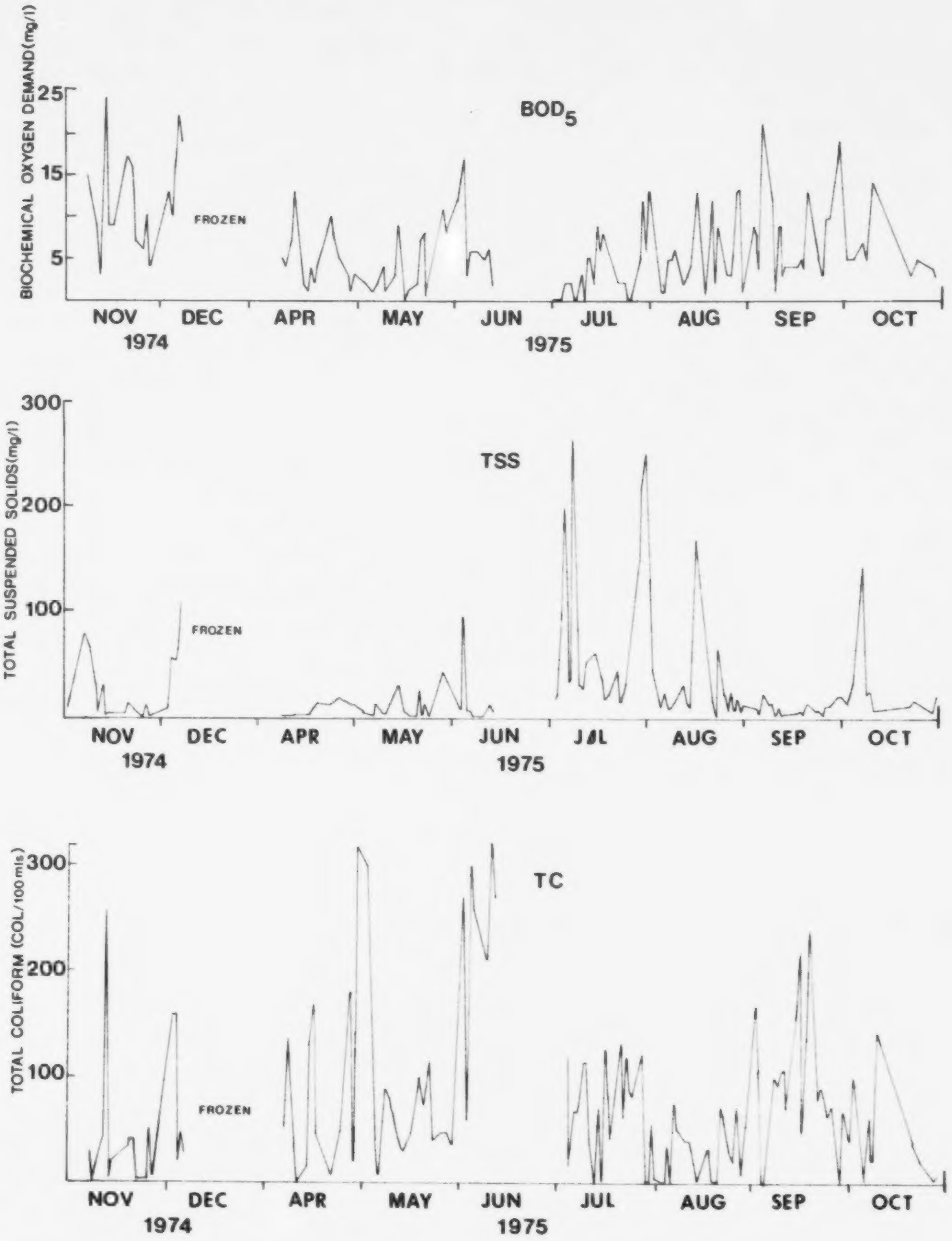


Figure 36. Total Coliform, Total Suspended Solids and Biochemical Oxygen Demand in Outlet Discharge Water

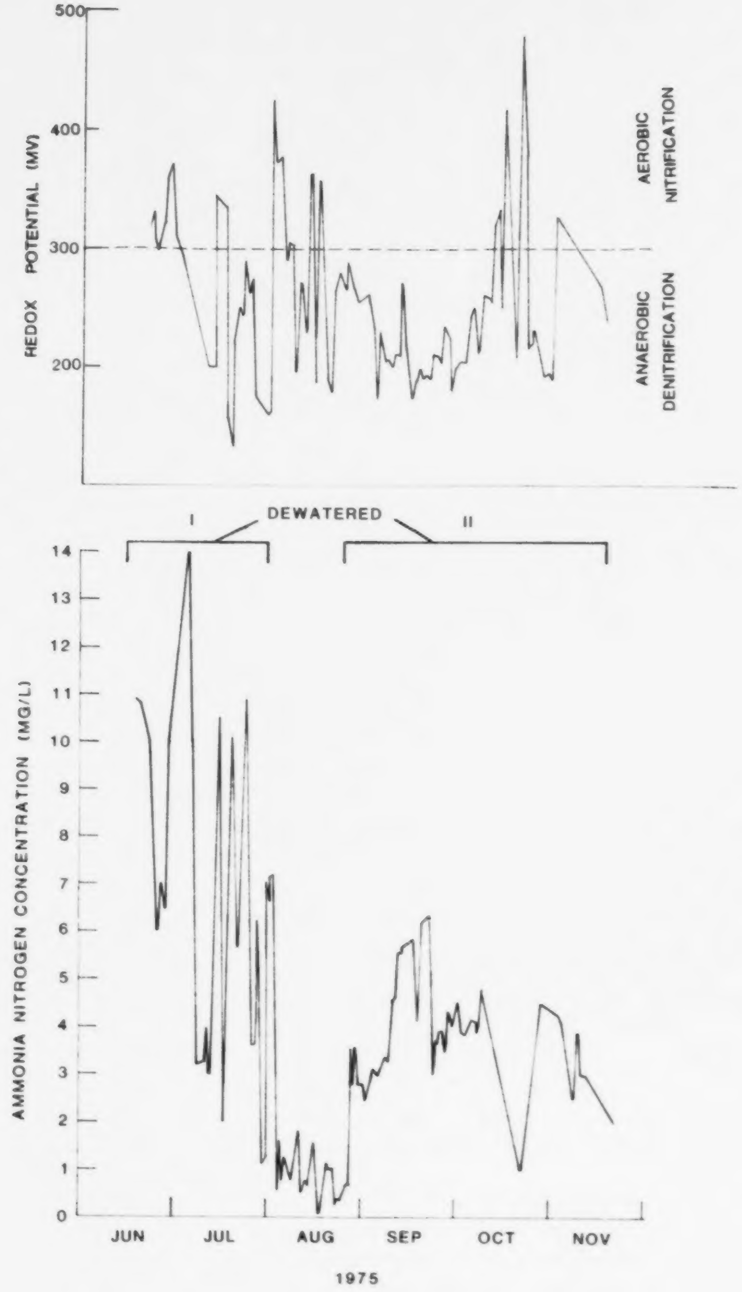


Figure 37. Ammonia Concentration and Oxidation Reduction Potential in Sump Discharge

tial in Sump Discharge. The fluctuating ammonia nitrogen concentrations observed in July were quite mysterious in light of the constant water levels over this period. It appears that the fluctuations observed are the result of nitrification and denitrification by bacteria. Nitrates were not measured but nitrification could occur as indicated by the oxidation reduction potential. Patrick found that an oxidation reduction potential of 300 or greater was necessary for nitrification (28). Through July this potential was exceeded several times corresponding to decreased ammonia nitrogen values. The fluctuating observed for oxidation reduction potential and ammonia nitrogen values may be due to the depletion of oxygen within the environment by the nitrifying bacteria followed by a replenishment of oxygen as the water aerates.

Water quality pumped from the pilot zone and sampled at the sump differed significantly from water quality sampled at the piezometers. The source of the sump is groundwater pumped from the upper three feet of soil. Ammonia nitrogen concentration appears to be affected most as can be seen by comparing Figures 37 and 38, Ammonia Concentration in Soil Water - Stations 3 and 9. Ammonia nitrogen concentration at the sump were generally half the ammonia concentrations of groundwater at the piezometer sump. This appears to point out the importance of aerating to improve the water quality. Further evidence of the pronounced effect of aeration was seen in August. The lysimeter was not pumped, groundwater was left standing in the holding tank over a three week period and sampled daily. Ammonia nitrogen concentrations were extremely low, 1-2 ppm, as this water was exposed to air. Upon exposure to air the ammonia nitrogen concentrations present as the dissolved ammonium ion may be volatized and lost as the gaseous form ammonia nitrogen to the atmosphere.

Dewatering of the pilot zone was done two times as indicated by the black bars on Figure 37. Through dewatering cycle I, ammonia nitrogen of the outlet and sump are within similar ranges and both fluctuate greatly. See Figure 37, page 87, and Figure 39, Ammonia Concentration in Outlet Discharge, for ammonia concentrations of sump and outlet. Peak concentrations of the sump and outlet correlate with the highest ammonia values occurring on the same day. The two cycles of dewatering differed significantly in resultant ammonia nitrogen concentrations.

During dewatering cycle II the ammonia nitrogen values of the sump are twice the concentration of the outlet. The higher ammonia values observed for dewatering cycle II in the pilot zone may be due to the increased activity of the soils microbes at station 4 in the pilot zone, as seen in carbon dioxide production, Figure 24, page 69. Less new cell synthesis was observed through the fall months but maintenance metabolism would be continuing. With less new growth or microbes, less nitrogen would be required but an energy source would still be needed,

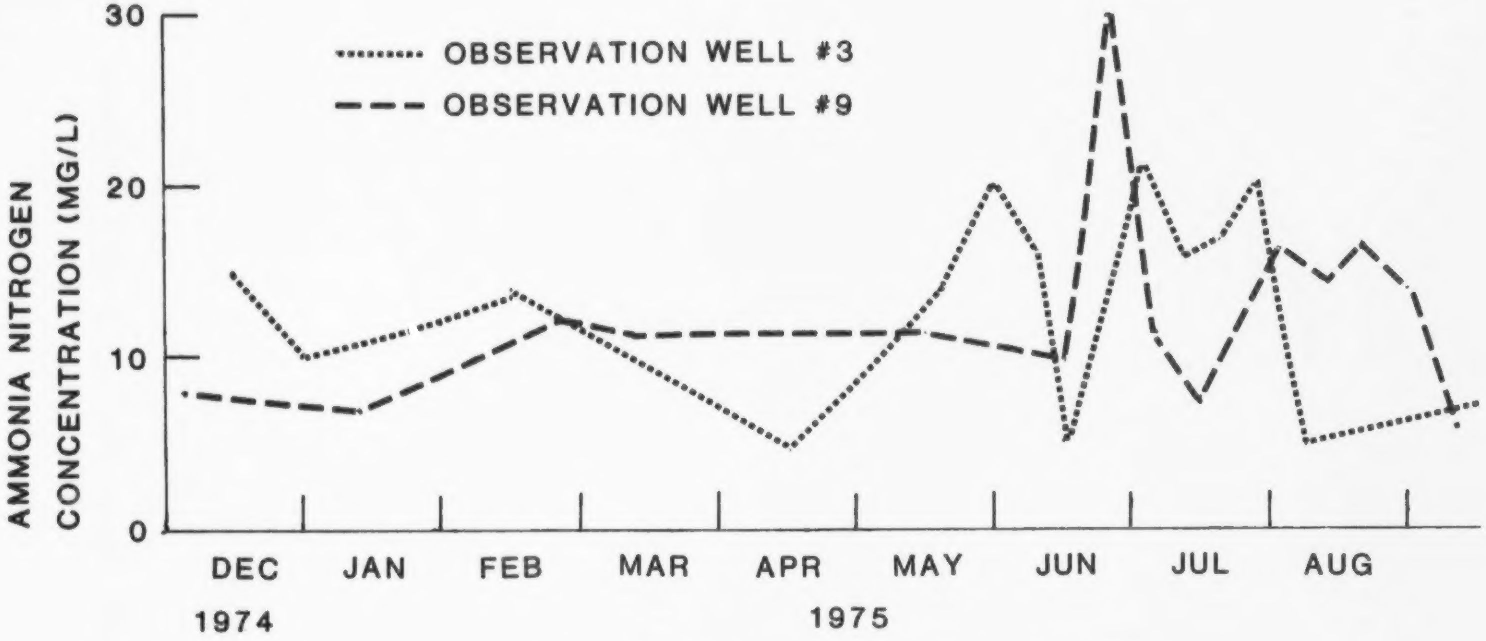


Figure 38. Ammonia Concentration in Soil Water - Stations 3 and 9

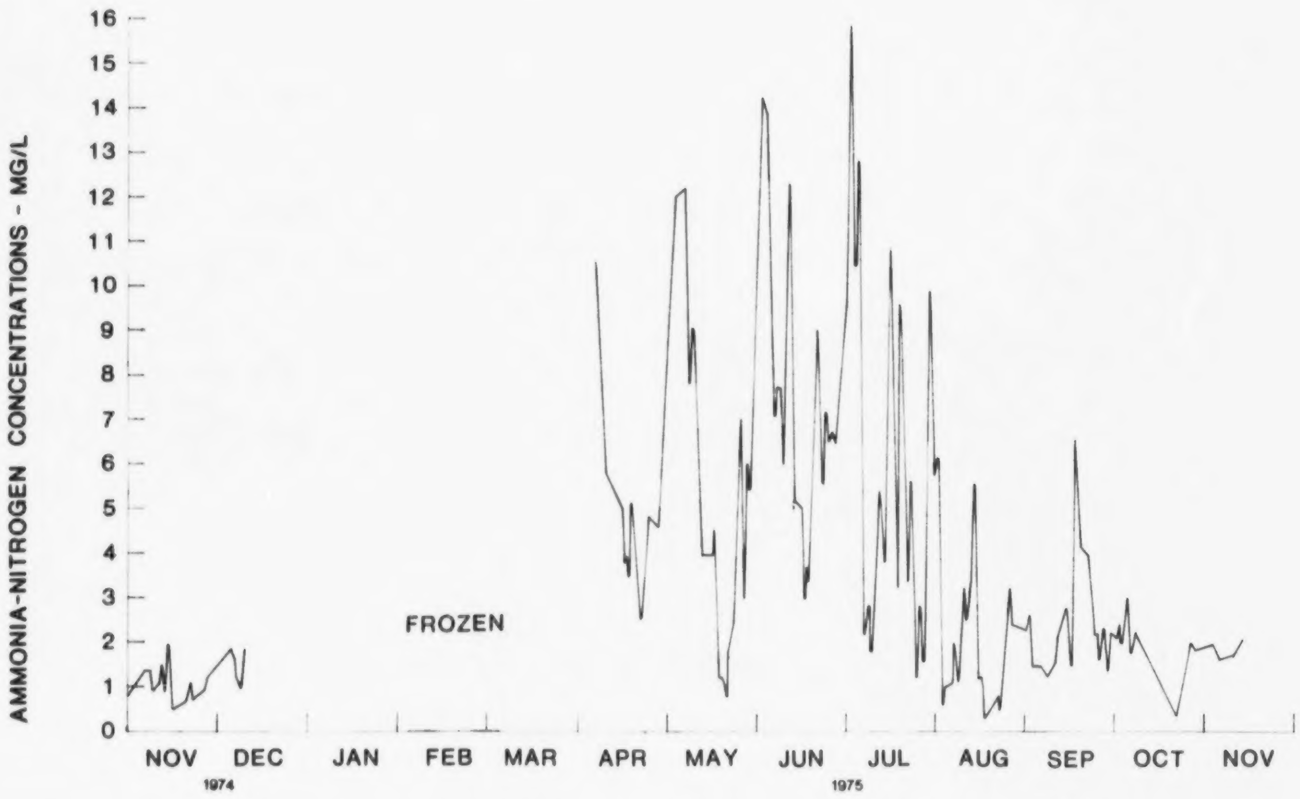


Figure 39. Ammonia Concentration in Outlet Discharge

producing carbon dioxide.

The greater quantity of organic material used by the microbes of the pilot zone, as observed in high carbon dioxide evolution over dewatering cycle II results in the subsequent release of ammonia nitrogen concentrations through deamination of the organic matter used as an energy source. The higher soil activity of the pilot zone consequently produces higher ammonia nitrogen in the sump.

Sump Water Quality - Total Phosphorus--

Total phosphorus concentrations of the sump ranged from 0.01 to 1.24 mg/l as shown in Figure 40, Total Phosphorus Concentration in Sump Discharge Water. A fluctuating pattern was seen, concentrations increased and decreased by a factor greater than two within a short period, one to two days. The phosphorus concentrations appear to be highly unpredictable. Through the period of July and September through October, water elevations were constant and phosphorus continued to fluctuate greatly indicating no direct relationship between water elevation and phosphorus.

Comparison of total phosphorus, pilot zone to control zone during dewatering cycle I shows similar ranges, however, peak concentrations for sump and outlet do not coincide. The outlet peaks lag the sump peaks by several days. See Figure 40 and Figure 41, Total Phosphorus Concentration in Outlet Discharge Water. This appears to indicate a mass movement of phosphorus carried by the groundwater through the wetland.

Through dewatering cycle II, higher concentrations of phosphorus were seen in the pilot zone over the control zone. It is uncertain as to whether this is related to the biological activity phenomena described for ammonia. Whereas ammonia is relatively constant over this period, phosphorus fluctuates greatly.

Phosphorus Ammonia Nitrogen Correlation--

There does not appear to be a direct relationship between phosphorus and ammonia nitrogen within the pilot zone for short term comparisons. This is best exemplified in the month of September, ammonia nitrogen concentrations are constant whereas phosphorus concentrations fluctuated. June through July both ammonia and phosphorus are fluctuating, however, the fluctuations do not appear to coincide.

Seasonally phosphorus and ammonia nitrogen concentrations do follow a similar pattern, higher concentrations were observed June through July, lower concentrations were observed September through November.

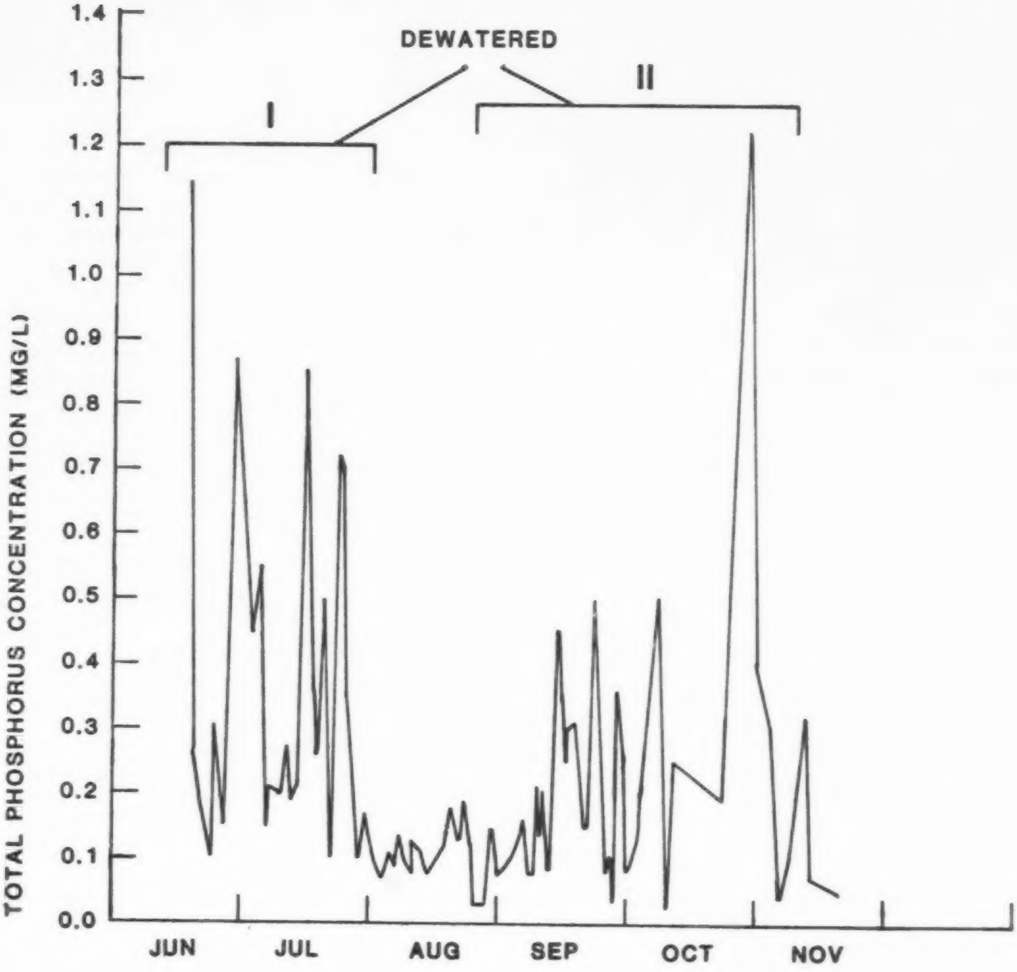


Figure 40. Total Phosphorus Concentration in Sump Discharge

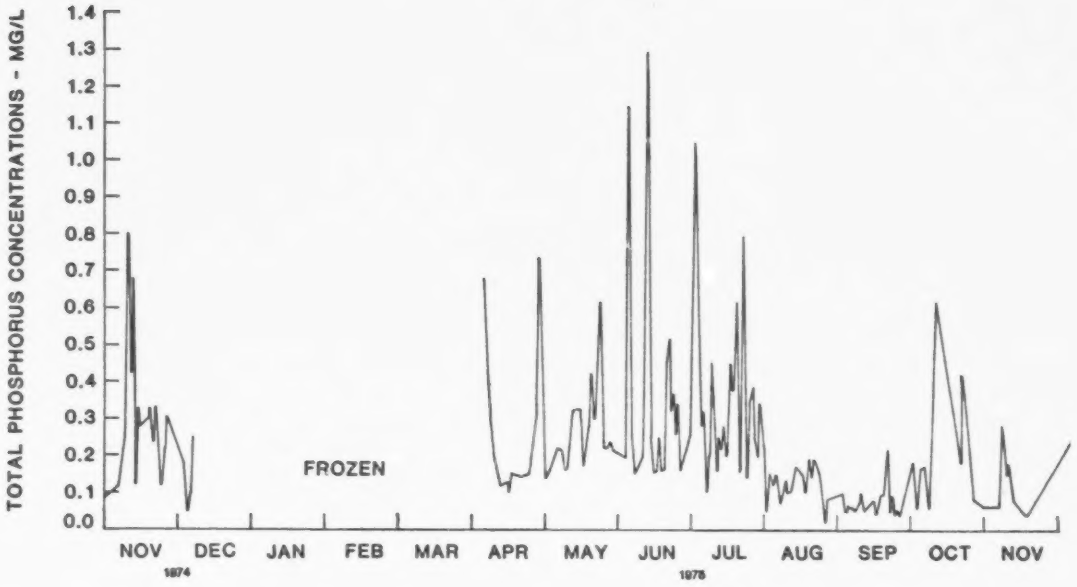


Figure 41. Total Phosphorus Concentration in Outlet Discharge Water

The ranges for samples taken throughout the year are in a ratio of nine ammonia to one total phosphorus, the accepted ratio of nitrogen to phosphorus in a biological system. This indicates that the majority of the nitrogen is of the ammonia form. The failure of ammonia nitrogen and phosphorus to correlate, short term, is probably due to the alteration of nitrogen states.

Where the wetland system is a contributing watershed to a recreational lake, it is desirable to reduce the nutrient flow to the lake. As the groundwater flows to the lake it carries this large load of nutrients to the lake. For an undisturbed system the inflow of nutrients would be desirable as a constant supply of nutrients in an equilibrium necessary to primary production and thus beneficial to fish and other aquatic life. However, many recreational lakes are out of equilibrium from poor sewage practices and thus unstable and unable to handle the nutrient load of groundwater.

SECTION 9

DISCUSSION

The hydrologic balance of the project watershed and wetland, although typical, present very complex problems relative to groundwater movement and losses from evaporation and evapotranspiration. The biological and chemical aspects of the ecosystem are closely related to the water level. High water levels create an anaerobic environment; an aerobic system is established with continuing low water levels. The state of the wetlands, aerobic or anaerobic, ultimately determines the type and amount of activity.

The wetland received water from the following three sources, with the percentage from each source shown in parenthesis; direct precipitation (35 percent), surface runoff (47 percent) and groundwater inflow (18 percent).

The losses from the wetland were by means of evapotranspiration (25 percent) and surface discharge (75 percent).

The sources of phosphorus, the major nutrient of interest, to the wetland were surface runoff (55 percent), groundwater inflow (44 percent) and precipitation (1 percent). Based on the mass balance equation, 78 percent of the phosphorus entering the wetland was removed, while 94 percent of the suspended solids were removed.

Review of the detailed environmental assessments, presented in Appendices A and B, indicate that no impacts were detected on the wildlife or vegetation as a result of this project.

The microbial activity within the wetland appears to be the most important mechanism influencing the improvement of the quality of the water passing through the site. The detailed investigations correlating microbial activity with water levels and total phosphorus concentration indicate that a rapid increase in microbial population follows the runoff events.

This process appears to follow the classic growth pattern exhibited in microorganisms in a batch culture. Initially, all nutrients are present in excess of the requirement of the microorganisms, and growth is unrestricted. During this period, called the constant growth phase, the concentration of microorganisms increases at an exponential rate. At some concentration, one of the nutrients becomes growth limiting and the culture proceeds into the declining growth phase. In response to the increasing competition of the microorganisms for the remaining limiting nutrient, the rate of growth decreases until growth finally halts. At this point, the limiting nutrient has been depleted and the replacement of those organisms that die is not possible. Consequently, the microorganism concentration decreases in what is termed the endogenous or auto-oxidation phase. When microorganisms are introduced to a growth medium to which they are unacclimated, there occurs prior to the constant growth phase, a lag phase in which the microorganisms become adjusted to the culture environment.

Modifications of the classic pattern occur as the results of varying ratios of nutrients to microorganisms in the culture medium.

After an initial lag phase, growth proceeds in the constant growth phase with the concentration of microorganisms increasing expotentially. The microorganisms remove from the culture nutrients required for growth, and the concentrations of the latter will decrease.

Organic material assimilated by a microorganism furnishes both the elements out of which protoplasm is constructed and the energy necessary for its synthesis.

The process found in the wetland appears to be one which involves an initial lag period, with a rapid growth period, followed by a declining growth period caused either by limited quantity of nutrients or by physical removal (by falling water levels) of the nutrients from the microorganisms activity sites.

Additional work in the area of optimizing the microbial processes is being performed, as part of the second portion of this grant, in organic soil filtration units and development of support data is anticipated.

The relative ineffectiveness of dewatering the wetland may be caused by the fact that additional acclimation is required once the stormwater is added to the system.

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APPENDIX A

ECOLOGY REPORT - PHASE I
(Status of the Biota at the Beginning of the Project)
by
James A. Jones, Ecologist

GENERAL COMMENTS

For some time it has been widely accepted that the wetland plays an important role in conditioning water which comes as runoff from the hard surfaces such as streets and parking lots. In some situations part of this water may be derived as surface drainage from highly fertilized lawns. Runoff water has been shown to be enriched with dissolved chemicals and it has the potential of carrying toxic agents. When this water flows directly into lakes the lakes tend to become overenriched resulting in undesirably heavy blooms of blue-green algae. It is proposed that the marsh functions as a biological filter system incorporating the undesirable agents from the water as it slowly filters through before entering the lake.

The present study is concerned with establishing specific values for the effects of the marsh on the drainage water; examining the feasibility of increasing the effectiveness of the marsh; and identifying the impact of the experimental procedures on the life of the marsh.

OBJECTIVES OF THE ECOLOGICAL STUDY

The specific objectives of the ecological portion of the study relate to measuring the biological effects on the marsh of the various controlled alterations of the environment. The study will include a vegetative analysis of the control and experimental plots and a faunal and floral analysis of the open-water marsh outside the plots to establish the original biological status and to identify any alterations in the biota accompanying and possibly induced by the experimental techniques.

THE EXPERIMENTAL AND CONTROL PLOTS

Description

The plots chosen for study meet the dictionary definition of "wetland" -- "a track of low, wet, soft land". The water level during this, a rather "normal", season (1974) has varied from a shallow covering in the early spring to about three feet below the surface in late July. Several showers in early August returned the water table to about six inches below the surface.

The substrate of the plots is of plant material in various stages of decomposition and preservation (as peat) with seemingly negligible but as yet undetermined siltation from runoff.

The vegetation of the plots is dense and represented by a variety of species which characterize the ecological age of the wetland. By growth form, species were identified as two trees, nine shrubs, three grasses, three sedges, and seventeen forbes. In initial appearance one is impressed by the predominance of willows, dogwoods, and reed canary grass.

The two plots are similar in species composition and in the relative abundance of the species. The homogeneity of the vegetation of the plots is further accentuated by the lack of marked zonation in species distribution although there is some clumping due to vegetative reproduction.

In general, the species are those common and widespread over central Minnesota. They are tolerant of the varied moisture conditions to which they are subjected in this habitat. Two species, *Typha latifolia* (cattail) and *Sagittaria sp*. (arrowleaf) are characteristic, and tolerant of higher water levels and may be near their dry-tolerance limit in this habitat partly because of the low water table at certain times and partly because of the severe competition provided by the reed canary grass and the various shrubs.

From the viewpoint of succession, the appearance of two species of trees on the plots, *Acer negundo* (box elder) and *Fraxians pennsylvanica* (green ash), and one species just off the plots, *Populus deltoides* (cottonwood) give evidence of the late stage of wetland succession. *Poa sp*. (bluegrass), *Eupatorium perfoliatum* (white boneset), and *Urtica gracilis* (stinging nettle) are tolerant of more dry conditions and are perhaps near the limit of their moisture tolerance in this habitat.

It should be noted that all species considered are hardy, tolerant, perennials and will be altered only by marked water-level alteration over an extended period of time.

Methods

Initial work on the vegetation analysis was begun in early July before I knew exactly the limits of the study plots. At that time plants were collected and identified from an extensive area of the wetland much of it lying outside the plots as they came to be surveyed and marked out later. All of the plants now found in the plots occur extensively outside the plots; only a couple of species found outside the plots do not occur within them. This indicates the representative nature of the study.

Several techniques for vegetation analysis were considered including the line transect, a one-meter wide transect, and random one square meter quadrants. When the study plots were designated their relatively small size, compared to viewing the entire marsh, made detailed mapping of conspicuous features seem the most functional. This was facilitated by the subdivision of the study plots into 25-feet wide subplots with the installation of tile for water level control.

Since the dense stand of the several species provides more than 100 percent cover it was impossibly confusing to place all plants on the same chart. Thus one chart includes trees and shrubs; a second includes reed canary grass and cattails; and a third includes conspicuous forbes and minor grasses and sedges.

Findings

The vegetation of the study plots is lush and varied. Thirty-eight species of plants have been identified as comprising the vegetative complex (see species list). No species has attained exclusive dominance over any extensive area although reed canary grass and the larger bush willows have succeeded in so doing to a limited extent. The distribution pattern for several species is to grow as a dense clone in one or more limited areas then as scattered individuals over a wider area. This pattern is exhibited by cattails, dogwoods, sedges, reed canary grass, purple loosestrife, black currant, purple bonest, and white boneset. Because these are the large and conspicuous forms, the distribution was most impressive. The herbs of lower growth forms undoubtedly display somewhat the same pattern in some cases but I was more impressed by their more scattered distribution under the overstory of the larger forms.

Black ash and box elder occur sparsely over the plots as young trees mostly less than four feet tall. Either the conditions are becoming more suitable for their germination and growth and they are about to take over as the next stage of succession or they are perpetually starting seedlings which grow for a couple of years than die out because of the environment. I believe the latter to be the case but it will be interesting to watch their response in relation to the experimental procedures to be carried out.

All species give the appearance of health and vigor. All are undergoing flowering and seed production (exclude two ferns and two trees).

Trampling, slashing, and ditching, as necessary activities of the project, are having an undetermined and unpredictable effect on about 15 percent of the marsh. Already, within two weeks from the time of disturbance due to slashing and trampling, recovery is apparent in some areas; the ditching effects may be longer lasting. In any event development on these disturbed areas will be observed and recorded.

See the accompanying list of species for plant composition and for plant distribution. The expressions for abundance, abundant (A), common (C), and rate (R) are subjective values and expressed on the basis of frequency of observation in relation to other species. If a species is present as isolated individuals but occurs widely over the plots it is classed as common. To be abundant the species occurs in dense stands and then as individuals over a wide area.

THE OPEN-WATER PORTION OF THE WETLAND

Description

The open-water area of the wetland is restricted to about one acre located near the center of the marsh. It was about eight inches deep when measured on August 16, 1974. Although the bottom at eight inches was capable of supporting the weight used for sampling (1 3/4 inch pipe coupling) it really represents the top of several feet of unconsolidated ooze and plant fragments.

The open-water is being reduced around the perifery by bog-like encroachment of surrounding vegetation. It was possible to approach the open-water within about ten feet by walking on the quaking roots. However, between these clusters of roots it was possible to thrust a lathe down five feet without contacting any firm bottom. By laying 4 x 8 sheets of 1/4-inch plywood on the quaking rooted plants it was possible to get to the very edge of the open water to take samples with dip nets and to dip samples for plankton analysis.

Methods

Sampling was performed from the edge of the open water. After much experimentation two techniques were established for sampling. Plankton was taken by holding a one-gallon plastic bucket on the end of a stick and allowing it to fill very slowly and carefully to avoid disturbance of the bottom ooze. This sample was then poured through a coarse-mesh insect net into the plankton net. The coarse-mesh net removed most of the duckweed and other floating material while the small plankters, it is felt, passed through relatively unaffected. The same technique will be used for the follow-up study.

Larger organisms including snails, fingernail clams, and insects, were collected by random thrusts with the insect net among the roots, bottom ooze, plant fragments and floating duckweed. This material was then worked over manually and the organisms picked out in the laboratory.

Finally life forms and activity on and about the marsh were observed and recorded.

Findings

The examination of the open-water portion of the marsh demonstrated conclusively that it is a healthful, living habitat. The limited span (season) of time over which the investigation was conducted (late July and early August) limit the organisms to those which were in "bloom" at that time. The highly organic quality of the environment further limits the species to those of special tolerance also. However, in spite of the limiting factors, great diversity of life forms is apparent.

At least two broods of ducks were reared on the marsh. One brood of five young woodducks with the mother and one brood of five young mallards with their mother were observed. Green herons, four at one time, were observed in July and August suggesting that they were reared there.

Many young toads, very recently metamorphosed, were observed on the higher marsh suggesting that they passed the tadpole stage in the marsh water. Leopard frogs are present near the water and over the marsh.

Anthropods were broadly represented in the collections. Back-swimmers, water scavenger beetles of two species, damselfly naiads, mosquito larvae and other diptera larvae were abundant. Cladocera were represented by Ceriodaphnia and Simocephalus. Copepods were represented by two cyclopid types identified to the genera Cyclops and Eucyclops. No live ostracods were collected although fossil shells occurred in the plankton collections suggesting their recent demise.

Mollusks were represented by three species of snails including Helisoma trivolvis, a small species of Stagnicola, and a Planorbula, and one species of fingernail clam in the genus Musculium.

Annelids were represented by at least three species; flatworms, one species; rotifers, seven species; porifera, one species; protozoa by fifteen species identified to genus and many species not identified; algae, by eight species identified to genus and many species of diatoms not identified.

The surface of the open water was completely covered by duckweed including *Lemna minor*, *Lemna trisulca*, and *Wolffia sp*. No submerged or floating leaved aquatic plants were observed in the open water.

Encroachment around the perifery is being accomplished by several species of plants including cattails, purple loosestrife, arrowleaf, smartweed, a mint, an umbelliferae, and a spike rush.

Quantitative determinations are restricted to the forms collected by straining a measured volume of water through the plankton net. The name "plankton" has been advisedly applied to thise category. Because of the few sexually mature adults (needed for species identification) and the many developing stages the two species of copeponds are simply referred to as cyclopids. Counts are as follows:

Organism	Number per liter	Organism	Number per liter
Phacus	150	Nauplius	1920
Monostyla	960	Cyclopidae	750
Lecane	420	Ceriodaphnia	Present
Lepadella	300	Simocephalus	Present
Platyias	340		
Salphina	300		
Diaschiza	30		

See the attached list of identified species. All in all I conclude that this is a healthy late-stage marsh community of a type found in abundance in the metropolitan area and over much of the state. Adequate evidence is available to evaluate any marked alteration in the quality of the environment caused by the experimental techniques of the marsh evaluation study.

REPRESENTATIVE LIST OF THE FLORA OF THE STUDY PLOTS

SCIENTIFIC NAME (or genus only)	COMMON NAME	ABUNDANCE (R, C, or A)
Acer negundo	Box Elder	C
Fraxinus pennsylvanica	Green Ash	C
Salix (2 spp.)	Willows	C
Cornus sp.	Dogwood	C
Ribes	Black Currant	C
Sambucus canadensis	Elderberry	C
Rubus pubescens	Swamp Raspberry	R
Vitis vulpina	Wild Grape	R
Rhamnus catharticus	Buckthorne	R
Viburnum opulus	Highbush Cranberry	R
Dryopteris thelypteris	Marsh Shield Fern	R
Onoclea sensibilis	Sensitive Fern	R
Phalaris arundinacea	Reed Canary Grass	A
Calamagrostis canadensis	Blue-joint Grass	C
Poa sp.	Blue Grass	R
Carex (3 spp.)	Sedges	R to C
Scirpus atrovirens	Leafy Bulrush	R
Typha latifolia	Cattail	A
Sagittaria sp.	Arrowleaf	C
Caltha palustrius	Marsh Marigold	R
Mentha arvensis	Peppermint	C
Lycopus asper	Water Horehound	R
Lycopus americanus	Water Horehound	R
Rumex sp.	Dock	R
Urtica gracilis	Stinging Nettle	R
Lysimachia thyrsiflora	Tufted Loosestrife	C
Eupatorium purpureum	Purple Boneset	C
Eupatorium perfoliatum	White Boneset	R
Impatiens capensis	Spotted Jewelweed	C
Lythrum salicaria	Purple Loosestrife	A
Asclepias incarnata	Swamp Milkweed	R
Stellaria longifolia	Long-leaf Chickweed	R
Campanula aparinoides	Marsh Bellflower	R
Solidago sp.	Goldenrod	R
Polygonum sagittatum	Tear-thumb	C
Epilobium sp.	Willowherb	R
Chelonia glabra	Turtlehead	R
Cirsium sp.	Thistle	R
Aster sp.	White Aster	R
Aster sp.	Purple Aster	R

REPRESENTATIVE OF ORGANISMS FROM THE OPEN-WATER PORTION OF WETLAND

Algae, Blue-Greens

Oscillatoria

Algae, Greens

Cosmerium
Closterium
Euglena
Trachelmonas
Phacus
Mougeotia
Oedogonium
Ulothrix

Algae, Diatoms (Many)

Protozoa, Amoeboid

Arcella
Centropyxis
Difflugia

Protozoa, Ciliates

Stentor
Stylonichia
Spirostomum
Chilodonella
Halteria
Frontonia
Cyclidium
Vorticella
Trachelophyllum
Paramecium
Coleps
Urocentrum

Protozoa, Flagellates

Peranema
Anthrophysa
Oikomonas
Monas
Bodo

Porifera

Spongilla fragillis
(Spicules only)

Flowering Plants on Water

Lemna minor
Lemna trisulca
Wolffia sp.

Flowering Plants in Water (None)

Rotifers

Rotaria
Platyias
Salpina
Monostyla
Diaschiza
Lecane
Lepadella

Platyhelminthes

Stenostomum

Annelida

Chaetogaster
Pristina
Another unidentified

Mollusca, Gastrapods

Helisoma trivolvis
Stagnicola
Planorbula

Mollusca, Pelecypoda

Musculium

REPRESENTATIVE OF ORGANISMS FROM THE OPEN-WATER PORTION OF WETLAND (cont.)

Crustacea, Cladocera

Simocephalus
Ceriodaphnia

Crustaces, Copepods

Cyclops
Eucyclops

Crustacea, Amphipods

Hyalella

APPENDIX B

ECOLOGY REPORT - PHASE II
(Status of the Biota After One Year)
by
James A. Jones, Ecologist

GENERAL COMMENTS

One year has elapsed since the initial examination of the vegetation of control and experimental plots and the faunal and floral analysis of the open-water portion of the wetland outside the plots. During this period the hydrologists, biologists, chemists and engineers of E. A. Hickok and Associates have completed installation of a superb array of water control and water monitoring devices and developed mechanisms for monitoring the activity of the microorganisms of the wetland substrate (and other).

Significant to the ecology portion of the study there has been a difference in the treatment given the experimental and control plots of the study area. The water level in the experimental plot has been lowered by pumping then allowed to fill again several times during the course of the year.

Significant also have been the fact that the spring and early summer have been exceedingly wet maintaining a somewhat greater amount of water over the whole wetland than normal. The relative effect of the natural phenomenon and the artificial controls will not be assessable. The effort of this portion of the study will be to identify any differences between the experimental and the control plots and to compare the present biota of the open-water wetland with that of one year ago.

THE EXPERIMENTAL AND CONTROL PLOTS

Methods for Reassessment

Plot maps of the 1974 survey were used to determine the lines followed in that survey. This was necessary because regrowth and recovery of the vegetation has been sufficient to obliterate the paths established in the installation of the tile and the plastic sheeting. However, conspicuous forms of vegetation such as trees, willow clumps and the larger herbs made it possible to orient myself at all times. Many specific plants on the lines and at points of intersection were identifiable. Using this technique for orientation I traced each of the trails three times--once for trees and shrubs, once for grasses, sedges and cattails, and once for other herbs. Many of the trails were covered additional times to double check and confirm impressions (see Figures 1, 2 and 3 for distribution of vegetation).

Vegetation of the wetland outside the control and experimental plots was examined also, especially as it pertained to willows.

Findings

Two generalizations can be made:

1. There are noticeable changes in the wetland.
2. There are no detectable differences in the changes between the test and control plots.

The larger willows have suffered the death of some major stems as well as of lesser branches. Careful examination shows that this is not a unique occurrence of this year but that major stems have died in years past not only on the study plots but over the wetland outside the plots. Older dead stems are on the ground by the willow clumps and overgrown with grasses of previous years. Dead and dying stems are found outside the study area in this wetland and in other wetlands in the metropolitan area. Vital young growth is apparent in most clumps.

There is an increase in the amount of touch-me-not (*Impatiens capensis*) in both the test and the control plots.

There is an increase in the number and vitality of the cattails in both plots; this is especially noticeable in the test plot because of the greater abundance of cattails there. Many more stems are producing seeds this year than last. New stems one to two feet tall are present in both plots.

There is an increase in the amount of mint (*Mentha arvensis*) related especially to the paths formed last summer. The slightly reduced competition of the previously well established cover due to last summer's disturbance probably gave the mint a better chance.

The several small (seedlings and saplings) ash (*Fraxinus sp.*) and box elder (*Acer negundo*) apparent last summer could not be found and no new ones were found this summer.

The reed canary grass appears to be acquiring even a greater dominance over the western half of the plot although this is difficult to establish. (Perhaps the clipping data will give some indication.) My impression may be prejudiced by the fact that no trails were established over most of the area this summer requiring me to break new trails through it.

Two other plants, though still rare are definitely more abundant, the wetland marigold (Caltha palustris) and the arrowhead (Sagittaria sp.).

Conclusions

Based on the information that I can bring to bear on the question I conclude that there is no difference in the response of the vegetation of the control and experimental plots resulting from the "difference in treatment" afforded them over the past year.

However, there are changes in both plots. While I am reluctant to hypothesize on the causes of the changes, the summation of the observations strengthens my feeling that the changes are definitely toward the direction of a greater amount of water. The woody plants (willows and trees and to some extent the red-ozier dogwood) are under stress while the more typically aquatic herbacious plants are thriving and increasing. The great majority of the species have a wide tolerance and are not noticeably affected, however.

Further, since both sides of the study area are similarly affected, I am confident that any effect on the vegetation that might have been apparent due to the experimental activity has been overridden by natural forces over the whole wetland.

THE OPEN-WATER PORTION OF THE WETLAND

Method of Reassessment

Sampling was performed from the edge of the open water as was done previously. It was necessary to place a new piece of plywood at the edge of the wetland for support. (Anyone approaching the open-water edge should be warned of the lack of any solid support for several feet into the bottom once the supporting root structure of the sedges and cattails is passed.)

The sample was taken using a dip net and a plankton net as was done for the original samples last summer. They were taken to the laboratory and examined under the dissecting scope then under the compound microscope as was done previously.

Findings

I can detect no significant difference in the open-water wetland in the two examinations. No ducks were observed on my single visitation but that is not to say there are none in the wetland. Last summer they were only seen once in several visits then only after a prolonged period of quiet observation.

No leopard frogs were observed.

More toads than last year were observed which indicates that conditions were satisfactory for amphibian reproduction.

The same anthropods, mollusks, and lesser animal phyla were observed in flourishing numbers, many of them in reproductive phases and developmental stages.

The surface of the open water is again covered by the three species of duckweed. Again no submerged or emergent rooted aquatics were apparent. The bottom is probably just too unstable to support rooted aquatics. Succession into the open water is from the periphery with the same formation as last year apparent.

No attempt is made at quantitative determinations this time but in scanning the microscope fields it is apparent that the same species are present. There are less nauplius stage copepods at this time but the adults of Cyclopidae are carrying egg sacs which will be developing into nauplius larvae shortly. Comparing the species list of 1974 with a list that might be prepared now, there is no significant difference. One additional algae (*Spirogyra*) is noted; one rotifer (*Rotaria*) was not observed; an additional cladoceran (*Pleuroxis*) and an additional copepod (*Ectocyclops*) were observed this year. It is apparent that the diversity index is high indicating a healthful community. Once this is established the number of species listed is directly proportional to the amount of time spent looking and the number of samples examined. Thus the deletion or addition of a few examples is not meaningful for our purpose here.

Conclusions

I conclude that the activity on the wetland over the past year has had no measurable effect on the life and vitality of the open-water portion of the wetland as measured by the composition of the biota of the plants and animals of the open water.

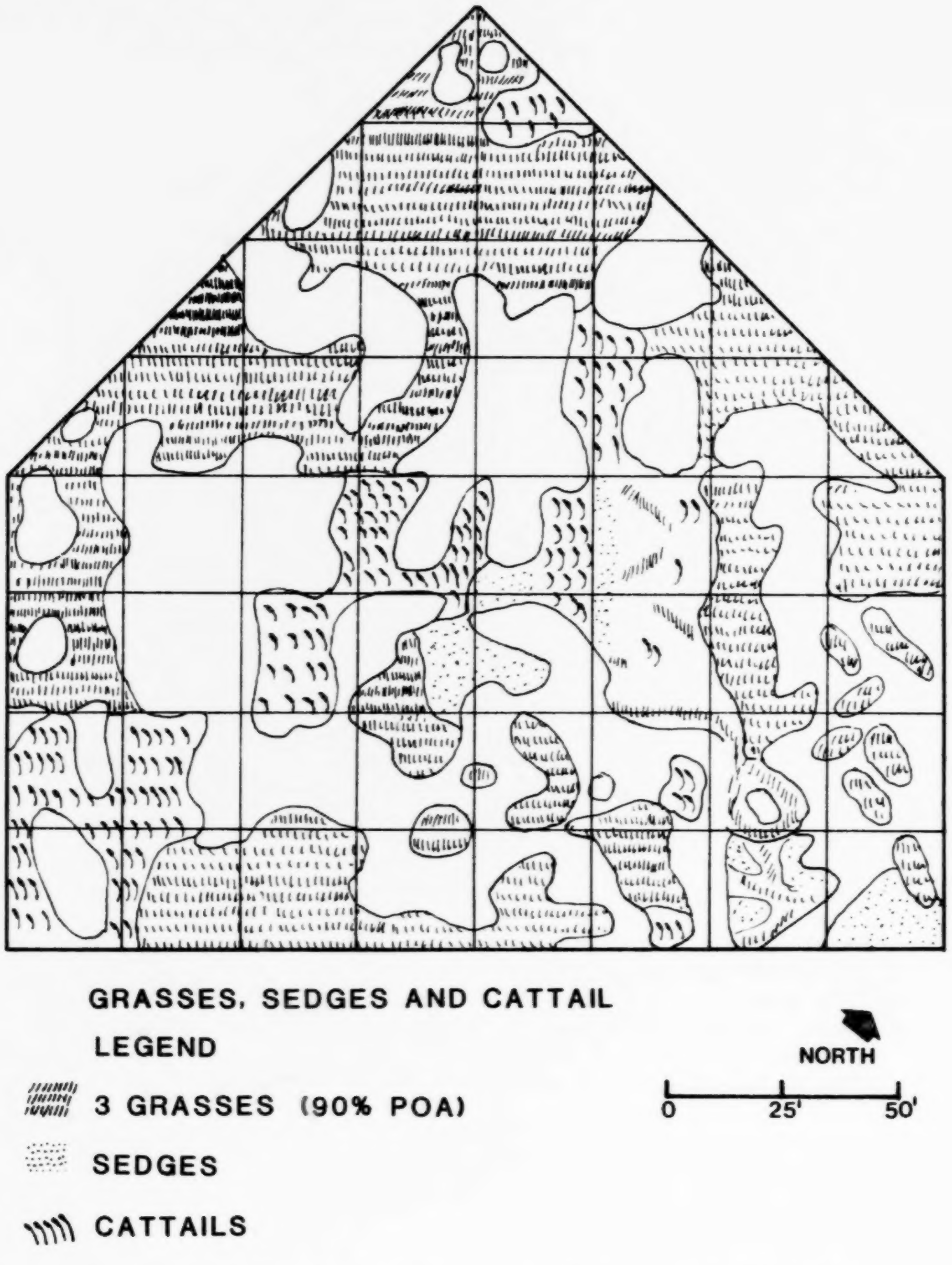
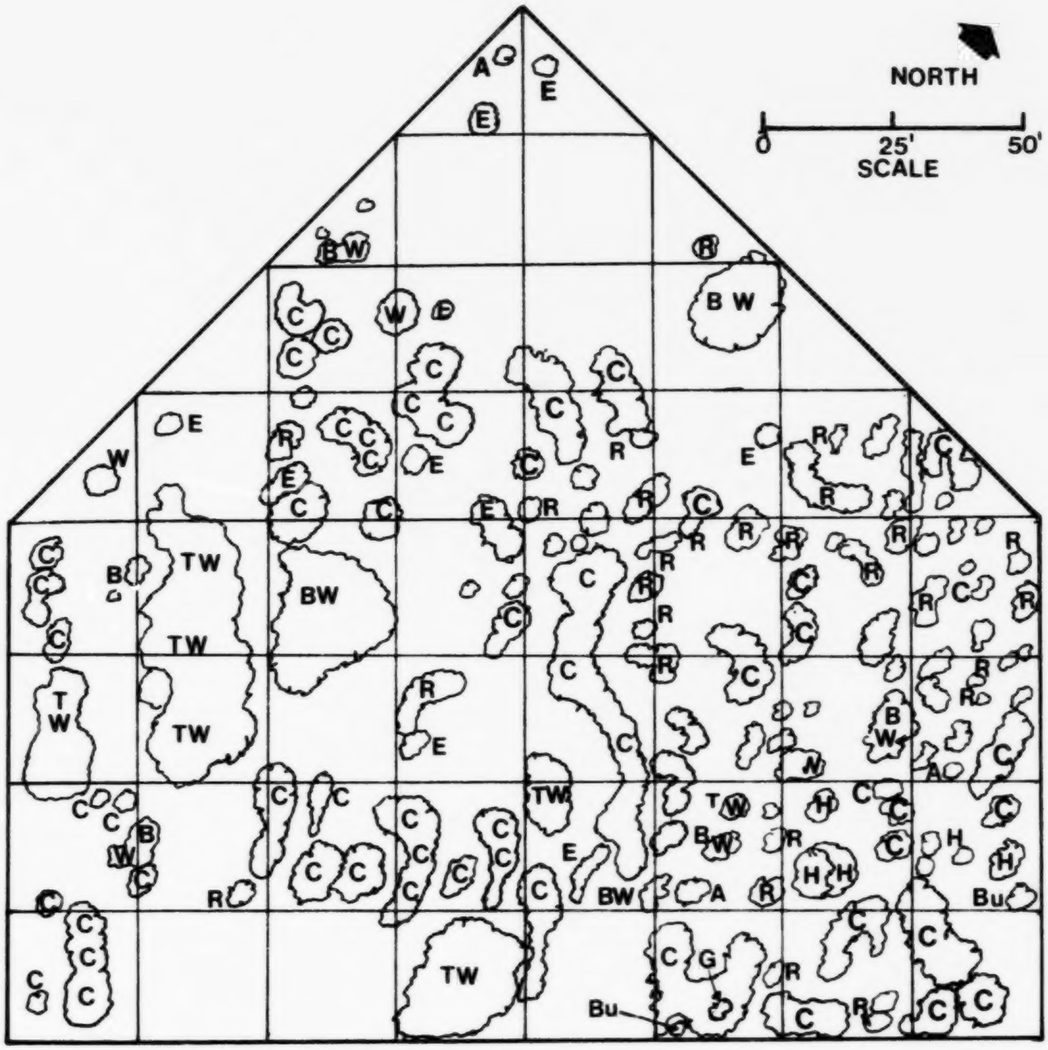

GRASSES, SEDGES AND CATTAIL
LEGEND
3 GRASSES (90% POA)
SEDGES
CATTAILS
NORTH
0
25'
50'

Figure 1. Distribution of Grasses, Sedges and Cattails


NORTH
0
25'
50'
SCALE
TW
BW
A
B
C
E
G
R
H
Bu

TREES AND SHRUBS

TW = SALIX SP.
A = FRAXINUS PENNSYLVANICA
B = ACER NEGUNDO
C = CORNUS SP.
E = SAMBUCUS CANADENSIS

G = VITIS VULPINA
R = RIBES SP
HC = VIBURNUM OPULUS
Bu = R. CATHARTICUS
BW = SALIX SP.

Figure 2. Distribution of Trees and Shrubs

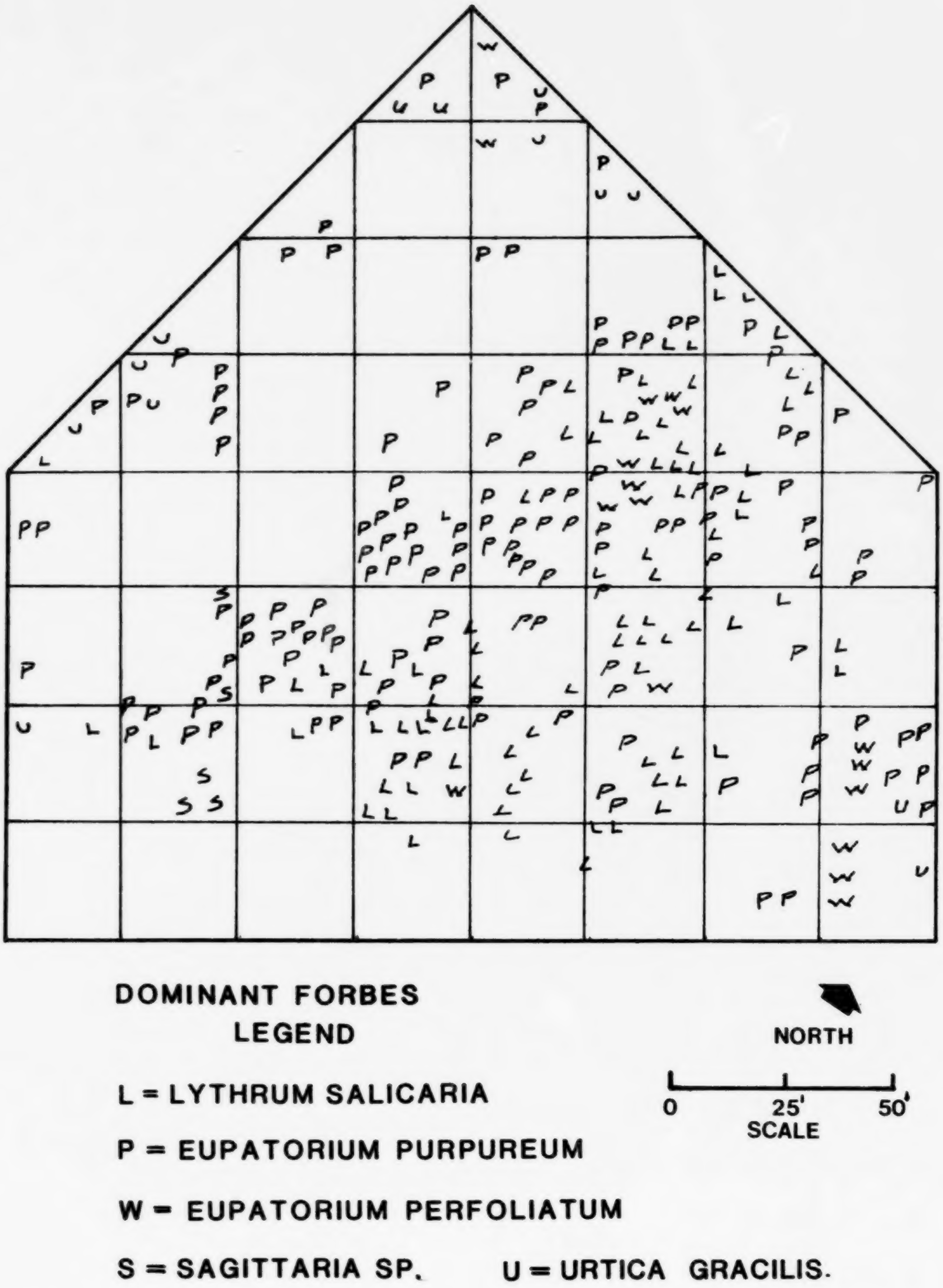

DOMINANT FORBES
LEGEND
L = LYTHRUM SALICARIA
P = EUPATORIUM PURPUREUM
W = EUPATORIUM PERFOLIATUM
S = SAGITTARIA SP.
U = URTICA GRACILIS.
NORTH
0
25'
50'
SCALE

Figure 3. Distribution of Dominant Forbes

APPENDIX C

METHODS OF SAMPLE COLLECTION AND ANALYSIS

OVERVIEW

All methods used in the performance of this project were in accordance with accepted methods specified by various agencies and organizations including the Environmental Protection Agency, U.S. Weather Bureau, U.S. Geological Survey, American Society of Testing Materials, University of Minnesota, American Public Health Association and the American Water Well Association.

SURFACE WATER QUALITY

All water samples were collected in 500 ml (0.13 gal) "whirl-pak" bags sterilized with ethylene oxide. Discrete samples of stormwater runoff were collected using automatic samplers, equipped with automatic starters, at 15 minute intervals.

Composite samples of stormwater runoff, where required, were prepared from the discrete samples. The volume of flow passing through each flume was used to prepare the composite samples.

Samples of water from the wetland pilot zone were collected at the sump both automatically and manually.

The analysis of all chemical parameters were performed in accordance with Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency (1974 Edition) (5) and Standard Methods for the Examination of Waste and Wastewater (13th Edition)(6).

TABLE 1. METHODS FOR ANALYSIS OF CHEMICAL PARAMETERS

Total Suspended Solids - Filtered through glass filter paper, dried at 103°C and weighed.
Ammonia Nitrogen - Nesslerization colorimetric analysis.
Total Phosphorus - Ammonia persulfate digestion with ammonium-molybate-ascorbic acid colorimetric analysis.
Biochemical Oxygen Demand - Dissolved oxygen change over five day incubation.

TABLE 1 (continued)

Total Coliform - Plate count on m-f Endo-Broth differential medium.

Oxidation Reduction Potential - Redox meter measurement.

SURFACE WATER QUANTITY

The quantities of water flowing into and out of the wetland were determined using auto-start Stevens Type F flow recorders mounted on parshall flumes. The flumes were calibrated and a stage-discharge relationship was used to determine the flow rates from stage measurements. The time factor was determined from the flow record.

GROUNDWATER

Groundwater levels were measured in the observation wells and expressed as centimeters below the soil surface. The top of the casings were determined from local benchmarks.

The observation wells were sampled by pumping the standing water from the well and allowing the wells to refill. A tygon tube was inserted through the top of the well and the sample pumped directly into the sampling container.

SOIL ACTIVITY AND ENVIRONMENT

Direct counts of microorganisms were taken from fresh soil suspensions stained with FITC and expressed as number of bacteria per gram of dry soil. Direct microscopy method utilized a sample taken from the natural environment, diluted quantitatively, and a known volume placed over a given area of microscope slide. Following appropriate staining, the preparation is examined under the microscope and all microorganisms in a given field of the microscope are counted. Recent improvements in the staining of microorganisms have greatly facilitated the detection and the differention of microorganisms from inert particles. Of particular usefulness is the method of staining with FITC followed by examination and enumeration by fluorescent microscopy. With this system, microbial cells react with the FITC and are visible due to the fluorescence subsequently emitted from those cells; inert and background particles do not react with the FITC and are not seen under the microscope. Both surface and subsurface soils were sampled.

Carbon dioxide evolution from the soil was measured *in situ*. The bottoms of one gal glass jars were removed and the jars inserted 5 cm (2 in) into the soil. When capped this created a closed chamber of fixed area to which the soil surface was exposed. A crucible was suspended from the lid, 10 mls of one normal (five normal over 72-hour period) solution sodium hydroxide was placed in the crucible and the lid screwed tight, after 24 hours, or 72-hours, the sodium hydroxide was quantitatively collected and carbonate ions precipitated with barium chloride. The sodium hydroxide was back titrated with standard hydrochloric acid and the milligrams of carbon dioxide absorbed was computed.

Soil temperatures were monitored throughout the sampling period at 12 stations. Soil temperatures at all stations were found to be the same on a given day within the wetland. A bimetallic thermometer was inserted 5 cm (2 in) into the soil and the temperatures recorded to the nearest Celsius degree.

The oxidation reduction potential of the soils was determined using platinum probes and a Corning AG3 portable pH meter.

OTHER

Precipitation data were collected using a Stevens Type SR and a Stevens Type QR recording precipitation gage.

Air temperature and relative humidity were recorded continuously using a Science Associates Model 257 hygrothermograph.

Wind velocity data were recorded continuously using Science Associates Model 436 and 442 anemometers with strip chart recorders.

Pan evaporation values were determined manually using a U.S. Weather Bureau hook gage and continuously using a Stevens Type F level recorder.

APPENDIX D

PENMAN METHOD FOR CALCULATION OF EVAPOTRANSPIRATION

$$H = E + A + S + C$$

where H = net radiant energy available at the earth's surface,
E = energy used in evaporating water,
A = energy used in hearing air,
S = energy used in hearing the water, and
C = energy used in heating the surroundings of the water.

He reasoned that energy used in heating the water and its container could be neglected and that the evaporation of water could be predicted from the equation.

$$E = H - A$$

Combination of this equation with Dalton's law results in an expression for E in which all needed values are available from meteorological data. The Penman equation is:

$$E = \frac{\Delta H + E_a\gamma}{\Delta + \gamma}$$

where E = evaporation from a free-water surface in mm/day,

$\Delta = \frac{de}{dT}_{Ta}$ = slope of the curve of vapor pressure at saturation versus air temperature, T_a, in mm Hg/^{o}F,

$$E_a = 0.35(e_s - e_d)\ \frac{0.5 + v_2}{100}$$

e_s = saturation vapor pressure at air temperature T_a in mm Hg,

e_d = actual vapor pressure of the air in mm Hg,

$$v_2 = \frac{\log 6.6}{\log h}\, v_h$$

where v_2 = average wind velocity in mpd at a height of 2 meters,
v_h = observed wind velocity at a height of h feet, and

H = net radiant energy available at the surface expressed in mm of water evaporated per day by that energy.

H is calculated from

$$H = R_a(1 - r)0.18 + \frac{0.55n}{N} - \sigma T_a^4(0.56 - 0.092\sqrt{e_d})$$

$$0.10 + \frac{0.9n}{N}$$

where R_a = mean extraterrestial radiation in mm of water per day,
r = radiation reflection coefficient (0.05 for water surface),
n/N = ratio of actual to possible hours of sunshine,
σ = Stefan-Boltzmann constant (2.01×10^{-9} mm day^{-1} $^{o}K^{-4}$),
T_a = air temperature ^{o}K (^{o}C, absolute),
e_d = actual vapor pressure of air, mm Hg, and
γ = constant in wet and dry bulk hygrometer equation (0.27 for temperature in ^{o}F and vapor pressure in mm Hg).

GLOSSARY

aerobic: describes an environment containing oxygen and microbes which grow in the presence of oxygen

anaerobic: describes an environment lacking in oxygen or microbes which grow in lack of oxygen

ecosystem: all interacting parts of the biological and non-biological community

eutrophication: the process of nutrient enrichment of a body of water in which an inbalance is created as nutrient concentrations increase at a faster rate than utilized by the biological community

evaporation: the physical process of water loss by heat energy conversion of water from the liquid to the gaseous state

evapotranspiration: the combined process of physical loss (evaporation) and biological loss, transpiration, of water from a system

fluorescene isothiocyanate total count (FITC): a staining procedure utilizing fluorescent and direct microscopic counts for differentiation and enumeration of bacteria in a soil suspension

mesophillic: describes the class of microorganisms which grow in the temperature range of 16-46°C, most soil microorganisms are of the mesophillic class

nitrification: the process of oxidation of nitrogenous compounds to nitrate in a soil system by a class of microorganisms known as nitrifying bacteria

phosphorus isotherm: the equilibrium curve of phosphorus in solution versus phosphorus sorbed to soil particles, over a range of concentrations. Each soil type has a characteristic phosphorus isotherm

sorbtion: the process by which nutrients are bound to soil particles by an ionic charge